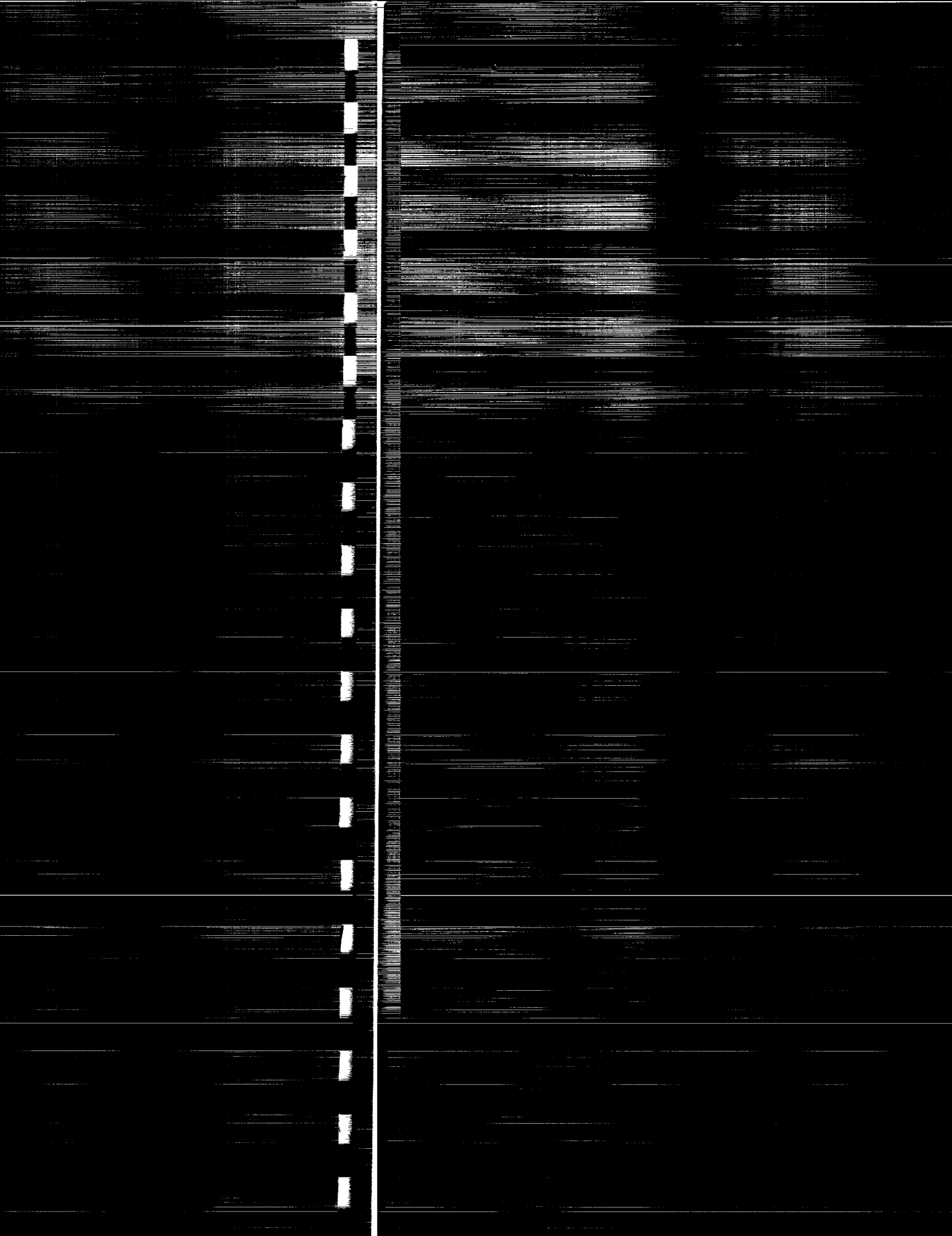

OAET

SSTAC/ARTS REVIEW OF THE DRAFT INTEGRATED TECHNOLOGY PLAN (ITP)

Volume VII: June 26-27

Computer Science, Data and Storage Communications

Briefings from the
June 24-28, 1991 Meeting
McLean, Virginia

National Aeronautics and Space Administration
Office of Aeronautics, Exploration and Technology
Washington, D.C. 20546

OAET

SSTAC/ARTS REVIEW OF THE DRAFT ITP
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Communications

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SSTAC/ARTS

Computer Science, Data & Software

External Review of the
Integrated Technology Plan for the Civil Space Program

DATA SYSTEMS & COMPUTER SCIENCE PROGRAMS

OVERVIEW

Paul H. Smith
Paul Hunter

June 26, 1991

Office of Aeronautics, Exploration and Technology
National Aeronautics and Space Administration

AGENDA

Wednesday, June 26, 1991 (Room a—Auditorium)

DSCS — DATA SYSTEMS & COMPUTER SCIENCE

External Review of the Integrated Technology Plan for the Civil Space Program
Data Systems & Computer Science
Tysons Corner Hilton, McLean, VA

Program Overview

8:00 am	Data Systems & Computer Science Programs	Paul Smith

Technical Presentations

9:05 am	Onboard Memory & Storage Technology	Tom Shull
9:30 am	Advanced Flight Computers	Harry Benz
9:55 am	Special Purpose Flight Processors	Mike Henry
10:15 am	Onboard Networking & Testbeds	Dan Dalton
10:30 am	BREAK	
10:45 am	Information Archive, Access, & Retrieval	Bill Campbell
11:10 am	Visualization	Ray Wall
11:30 pm	LUNCH	
12:30 pm	Neural Networks	Sandeep Gulati
1:00 pm	Software Engineering	Art Zygielbaum
1:30 pm	Flight Control & Operations	Paul Messina
2:00 pm	Discussion / Caucus	
2:30	ADJOURN	

Revised AGENDA

Wednesday, June 26, 1991 (Room A—Auditorium)

DSCS — DATA SYSTEMS & COMPUTER SCIENCE

External Review of the Integrated Technology Plan for the Civil Space Program
Data Systems & Computer Science
Tysons Corner Hilton, McLean, VA

Program Overview

9:45 am	Data Systems & Computer Science Programs	Paul Smith

Technical Presentations

10:45 am	Onboard Memory & Storage Technology	Tom Shull
11:05 am	Advanced Flight Computers	Harry Benz
11:25 am	Special Purpose Flight Processors	Mike Henry
11:45 am	Onboard Networking & Testbeds	Dan Dalton
12:00	LUNCH	
1:00 pm	Information Archive, Access, & Retrieval	Bill Campbell
1:20 pm	Visualization	Ray Wall
1:40 pm	Neural Networks	Sandeep Gulati
2:05 pm	Software Engineering	Art Zygielbaum
2:30 pm	Flight Control & Operations	Paul Messina
2:55 pm	Discussion / Caucus	
3:15 pm	ADJOURN	

6/25/91 6:27 PM

OUTLINE

DSCS — DATA SYSTEMS & COMPUTER SCIENCE

- Setting
- Recommendations and Needs
- Introduction to Program
  - — Program Goals and Objectives
  - — Program Structure
  - — Benefits/Payoffs
- Program Description: Ongoing
  - Accomplishments
  - Facilities
  - Products/Deliverables: Ongoing
- Program Description: Strategic Plan
  - Technology Challenges
  - Related Programs
- Budget
- Program Description: 3x Budget Plan
  - Product / Deliverables: 3x Budget Plan
  - Product / Deliverables: Strategic Plan
- Key Issues
- Summary

6/25/91 2:19 PM

PROGRAM MATRIX

	BASE R&T		FOCUSED PROGRAMS				
			OPERATIONS			*SPACE SCIENCE*	
DSCS PROGRAM COMPONENTS	UNIVERSITY PROGRAMS	COMPUTER SCIENCE	SPACE DATA SYSTEMS	GROUND DATA SYSTEMS	FLIGHT CONTROL & OPERATIONS	ARCHIVE, ACCESS & RETRIEVAL	VISUALIZATION
SPACE DATA SYSTEMS	X		X				
SCIENCE INFORMATION SYSTEMS	X	X				X	X
NEURAL NETWORKS	X	X					
SOFTWARE ENGINEERING	X	X		X			
FLIGHT CONTROL & OPERATIONS					X		

RECOMMENDATIONS: facing page

- "Recommendation 8: That NASA, in concert with the Office of Management and Budget and appropriate Congressional committees, establish an augmented and reasonably st able share of NASA's total budget that is allocated to advanced technology development. A two- to three-fold enhancement of the current modest budget seems not unreasonable. In addition, we recommend that an agency-wide technology plan be developed with inputs from the Associate Administrators responsible for the major development programs, and that NASA utilize an expert, outside review process, managed from headquarters, to assist in the allocation of technology funds." (Augustine Report, 1990)
- "The consequences of neglecting the technology base are very measurable indeed, not only impacting America's competitiveness but inducing major projects to be undertaken without a sufficient technological foundation in place. When problems are subsequently encountered, these projects must be restructured, usually accompanied by an increase in cost. ... It seems clear that our technology base, including its supporting facilities, must be revitalized and afforded priority commensurate with its importance if major new projects are to be pursued on a realistic bases in the decades ahead. (Augustine Report, 1990)
- " Unlike research, which seeks new knowledge, technology is concerned with the application of that knowledge to useful purposes. The development of advanced technology is thus crucial to the success of the exploration and exploitation of space - whether human or robotic." (Augustine Report, 1990)
- "Facilitiate insertion of new technology at all program stages ... clarify and consolidate required space qualification procedures" (SSTAC, Ad Hoc Committee on Spacecraft Computer Technology, 1990)
- "NASA should support the development of portable, distributed, user-friendly, transparent observation planning tools. These should be consistent with the telescience concepts of remote mission planning and operations." (Astrotech 21, 1991)
- "The potential for direct operation of small missions or experiments should be studied. This would allow more efficient interaction between the user and the facility, and could reduce costs" (Astrotech 21, 1991)

RECOMMENDATIONS

External recommendations to NASA

- "Create a spacecraft computer technology applications activity to provide a mature, program-independent technology base and/or set of spacecraft computer building blocks for program-specific requirements" (SSTAC, Ad Hoc Committee on Spacecraft Computer Technology, 1990)

- "The mission needs for onboard processing anticipated over the next 10 to 20 years equal and in some cases exceed today's [ground-based, state-of-the-art computer] capability. ... NASA needs a research program to address these computing issues and focus on design or qualification of autonomous space computing systems." [Aeronautics and Space Engineering Board (ASEB), (1987)]

(Continued next page)

RECOMMENDATIONS

(continued)

- The next decades will bring "an explosion in the volume of information gathered in space and a need for automated pre-processing and rapid and wide dissemination of information products" (ASEB, 1987)

- "Software engineering has become as important to the success of a new instrument as are mechanical, electrical, or optical engineering." (Bachall Report, 1991)

- "It is desirable that an automated science analysis system, as part of science operations, direct the scientists attention and effort towards "interesting" data and facilitate its interpretation." (Astrotech 21, 1991)

- "NASA must modernize its mission operations and communications infrastructure, including distributed operations concepts and direct reception of data." (Astrotech 21, 1991)

CUSTOMER NEEDS

(FACING PAGE)

- Teams established in Space Research and Technology Thrust areas (e.g., Operations, Space Science)

- Prioritization of technology needs from NASA user codes used as input in determining commonality across missions
  - Office of Space Science and Applications (OSSA)
  - Office of Space Flight (OSF)
  - Office of Space Operations (OSO)

- Decision criteria used to prioritize focused technology needs within the Office of Aeronautics, Exploration, and Technology (OAET)
  - Mission need
  - Key research areas coverage
  - Programmatics & timing
  - Special issues

- The Neural Nets Base R&T program supports both Space Data Systems and Science Information Systems

- Operations Thrust provides cross-cutting Technology
- Address only highest priority elements

INTEGRATED TECHNOLOGY PLAN FOR THE CIVIL SPACE PROGRAM

"Strategic Plan" ITP: CSTP Element Categorization

OAET

	HIGHEST PRIORITY ◊◊◊			2nd-HIGHEST PRIORITY ◊◊			3rd-HIGHEST PRIORITY ◊		
Space Science Technology	Submillimeter Sensing	Direct Detectors	Active µwave Sensing	Sample Acq., Analysis & Preservation	Passive Microwave Sensing	—	Optoelectrnics Sensing & Processing	Probes and Penetrators	—
	Cooler and Cryogenics	Microprecision CSI	Laser Sensing	Telescope Optical Systems	Sensor Electronics & Processing	—	Precision Instrument Pointing	Sensor Optical Systems	—
		Data Visualization	Data Archiving and Retrieval						
Planetary Surface Exploration Technology	Radiation Protection	Regenerative Life Support (Phys-Chem.)	Space Nuclear Power (SP-100)	High Capacity Power	Planetary Rovers	Surface Habitats and Construction	Exploration Human Factors	—	Artifical Gravity
	—	—	Extravehicular Activity Systems	Surface Solar Power and Thermal Mgt.	In Situ Resource Utilization	Laser-Electric Power Beaming	Medical Support Systems	—	—
Transportation Technology	ETO Propulsion	Aeroassist Flight Expt	Aeroassist/ Aerobraking	Transfer Vehicle Avionics	ETO Vehicle Avionics	ETO Vehicle Structures & Materials	Autonomous Rendezvous & Docking	COHE	Auxiliary Propulsion
	Cryogenic Fluid Systems	Nuclear Thermal Propulsion		Nuclear Electric Propulsion	CONE	SEPS TPE	Autonomous Landing	TV Structures and Cryo Tankage	HEAb
		Adv. Cryo. Engines	Low-Cost Commercial ETO XPort						
Space Platforms Technology	Platform Structures & Dynamics	Platform Power and Thermal Mgt.	Zero-G Life Support	Platform Materials & Environ. Effects	Station-Keeping Propulsion	—	Spacecraft On-Board Propulsion	Earth-Orbiting Platform Controls	Advanced Refrigerator Systems
	—	—	Zero-G Advanced EMU	Platform NDE-NDI	Deep-Space Power and Thermal	—	Spacecraft GN&C	Debris Mapping Experiment	—
Operations Technology	Space Data Systems	High-Rate Comm.	Artificial Intelligence	Ground Data Systems	Optical Comm Flight Expt	Flt Control and Operations	Space Assembly & Construction	Space Processing & Servicing	Photonics Data Systems
	—	CommSat Communicat'ns	TeleRobotics	FTS DTF-1	Navigation & Guidance Operator Syst./Training	CommSat Communicat'ns Flight Expts	—	Ground Test and Processing	—

OBJECTIVES

(FACING PAGE)

DSCS — *DATA SYSTEMS & COMPUTER SCIENCE*

SPACE DATA SYSTEMS

- Increase data transport capabilities
- Improve performance while decreasing critical spacecraft resource usage: mass, power, and volume
- Reduce mission operation / planning efforts
- Reduce design, development and testing costs
- Increase life expectancy, reliability, and fault tolerance

SCIENCE INFORMATION SYSTEMS

Access & Retrieval

- Rapid archiving of data sets
- Automatic characterizing & labeling of data in near-real time
- Efficient and effective data and content browse
- Rapid electronic distributed data access
- Alert users to anomalies in data automatically

Visualization

- Interactive navigation of observed and modeled data
- Interactive simulation for mission/instrument design

SOFTWARE ENGINEERING

- Improve ability to manage development, operation, and maintenance of complex software systems
- Decrease NASA's cost and risk in engineering complex software systems
- Provide technology to assure safety and reliability of software in mission-critical applications

NEURAL NETS

- 100x speed up over SOA for ground-based, simulation of complex phenomena
- 100x speed up of onboard, large-scale science data reduction
- Vehicle health monitoring

FLIGHT CONTROL & OPERATIONS

- Mission control test-bed
- Command sequence generation and validation
- Spacecraft simulation
- Quick-look capability
- Network technology for congestion-resistant, fault-tolerant computer networks

PROGRAM GOAL & OBJECTIVES

DSCS — *DATA SYSTEMS & COMPUTER SCIENCE*

GOAL

- Provide the next generation onboard and ground data systems technology to enable and enhance NASA's Science and Exploration missions

OBJECTIVES

- Develop high-performance, space-qualifiable, onboard computing, storage, and networking technologies
- Develop technology for automated characterization, and interactive retrieval and visualization for very large, complex scientific data sets
- Advance NASA's ability to cost effectively develop and support complex and very reliable software systems
- Demonstrate potential of high-risk / high-payoff neural processing for NASA applications
- Adapt and demonstrate selected advanced computing technologies for mission operations

BENEFITS/PAYOFFS

facing page)

- Make available to future missions the technology for a fully space-qualified, RAD-hard, SEU-immune, 32-bit computer with the computational power needed to meet projected mission requirements
- Demonstrate a space-qualifiable optical disk recorder with capacity expandable to terabits, solid-state block access recorder technology, and non-volatile RAM technology to satisfy the expanding onboard storage requirements of future missions
- Provide space-qualifiable, low-power, high-performance, special purpose processors that enable real-time information extraction and onboard image processing:
  30 mW/channel, 5 MHz digital autocorrelator spectrometer breadboard;
  Engineering versions of 1000 MHz autocorrelator and corss correlator chips
- Enable a significant increase in scientific productivity using advanced technologies in archiving, retrieval, and visualization of terabytes of complex scientific data
- Develop programming techniques designed to decrease cost and schedule risk of software development
- Explore the potential for systems with 100-10,000x greater performance, intrinsic fault/noise immunity, and adaptability through the use of neural network technology
- Develop improved mission-control information processing capabilities to meet requirements for future mission control centers (concurrent missions, data quick look, rapid response to targets of opportunity).

BENEFITS / PAYOFFS

- Reduced risk to NASA Projects for inserting advanced enabling computing technology
- Advanced space-qualifiable data systems technology that will enable the more aggressive data requirements of future NASA missions
- Expanded capability fo NASA researchers to access and analyze massive amounts of data
- Predictable and controllable software processes for the efficient production of complex, reliable software systems

PROGRAM STRUCTURE

DATA — DATA SYSTEMS & COMPUTER SCIENCE

"STRATEGIC PLAN"

UNIVERSITY PROGRAMS	BASE R&T COMPUTER SCIENCE	FOCUSED PROGRAMS	PRESENTATIONS
VLSI CENTER AT U. OF IDAHO		SPACE DATA SYSTEMS	SPACE DATA SYSTEMS • Onboard Memory & Storage • Advanced Flight Computers • Special Purpose Flight Processors • Onboard Networking & Testbeds
CASIS AT STANFORD	INFORMATION MANAGEMENT	SCIENCE INFORMATION	SCIENCE INFORMATION SYSTEMS • Archive, Access, & Retrieval • Visualization
	NEURAL NETS		NEURAL NETWORKS
RICIS AT THE U. OF HOUSTON, CLEARLAKE	SOFTWARE ENGINEERING	SOFTWARE FOR OPERATIONS SUPPORT	SOFTWARE ENGINEERING
		FLIGHT CONTROL & OPERATIONS	FLIGHT CONTROL & OPERATIONS

PROGRAM STRUCTURE

DSCS — DATA SYSTEMS & COMPUTER SCIENCE

"ONGOING"

UNIVERSITY PROGRAMS	BASE R&T COMPUTER SCIENCE	FOCUSED PROGRAMS	PRESENTATIONS
VLSI CENTER AT U. OF IDAHO		SPACE DATA SYSTEMS	SPACE DATA SYSTEMS • Onboard Memory & Storage • Advanced Flight Computers • Special Purpose Flight Processors • Onboard Networking & Testbeds
CASIS AT STANFORD	INFORMATION MANAGEMENT		SCIENCE INFORMATION SYSTEMS • Archive, Access, & Retrieval • Visualization
	NEURAL NETS		NEURAL NETWORKS
RICIS AT THE U.OF HOUSTON, CLEARLAKE	SOFTWARE ENGINEERING		SOFTWARE ENGINEERING

ACCOMPLISHMENTS

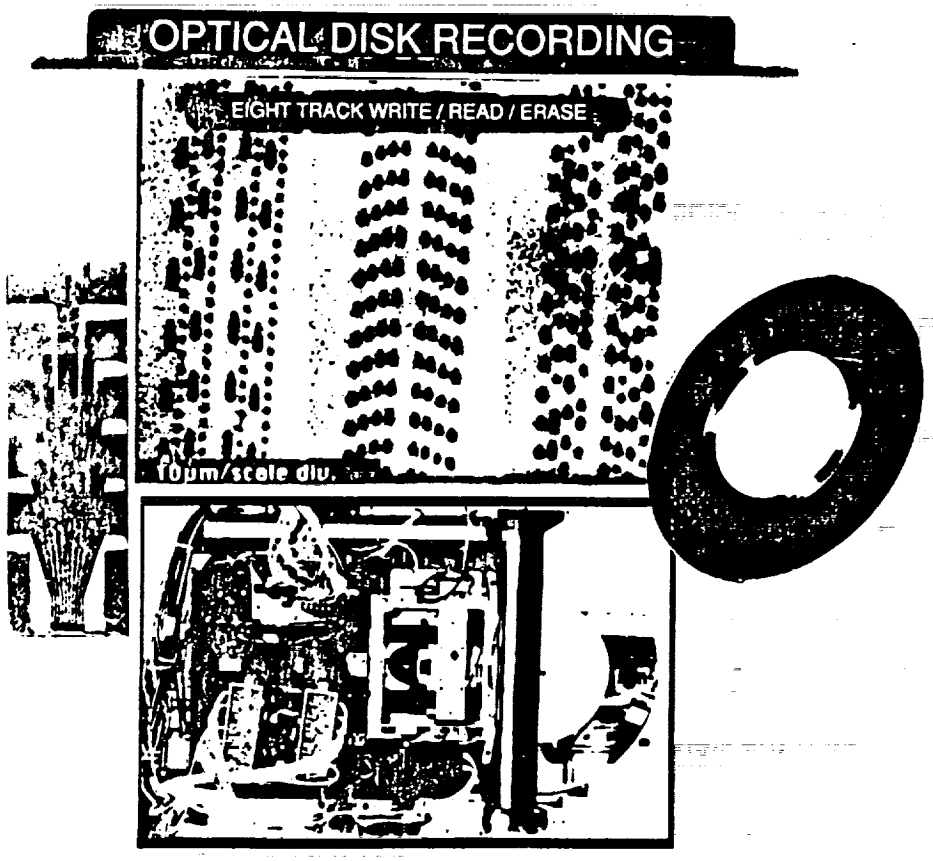
- Demonstrated 8-track, magneto-optical write-read-erase capability on 14-inch media with 9-element diode laser array (SODR) (1990)
- The Magellan Imager is operationally using the Advanced Digital SAR Processor (ADSP) initially developed under the CSTI Data Systems program
- The CRAF / Cassini Imaging System is baselined with a custom version of the Image Spectrometer Flight Processor (ISFLIP) data compressor developed under the CSTI Data Systems program
- Developed and demonstrated intelligent user interface (IDM) for the International Ultraviolet Explorer database and EOSDIS (1991)
- Tested and evaluated prototype of astrophysics data management system (DAVID) for distributed and heterogeneous computer systems (1991)
- Demonstrated automatic auroral images analysis with more than 10x improvement over previous analysis techniques for the Dynamic Explorer data (CASIS) (1991)
- Software management environment (SME) tool transitioned to satellite attitude software developers for evaluation and user feedback (1991)

(Continued next page)

ACCOMPLISHMENTS

(continued)

- Software Engineering Research Center, under Code RC funding, crucial in selecting Ada for Space Station Freedom (1985-1986)
- Developed analog Neural Synaptic Array chip (1990)
- Developed and demonstrated Neural StarTracker (1988)
- World's first demonstration of sparse distributed memory (SDM) prototype (1989)
  - — Application of (SDM) to handwritten character recognition (1990)
- Developed conceptual prototype of Encyclopedia of Software Components (1990)
- Developed Configurable High-Rate Processor System (CHRPS) (1990)
- Created the Center of Excellence in Space Data and Information Sciences (CESDIS) at GSFC on a cooperative program with the University of Maryland; Special projects involve principal investigators from universities across the United States (1988)


OPTICAL DISK RECORDING
EIGHT TRACK WRITE / READ / ERASE
10μm/scale div.

PUBLIC INFORMATION OFFICE
JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
PASADENA, CALIF. 91109. TELEPHONE (818) 354-5011

PHOTO CAPTION

Magellan
P-36644 MGN-12
9/17/90

On September 15, 1990, the Magellan spacecraft started radar operations for its mapping mission at Venus. This image is taken from the first set of radar data collected in the normal operating mode. These fault-bounded troughs were imaged by Magellan on orbit 377 on Sept. 15, 1990. The image is of part of the Livinia Region of Venus at 60 degrees south latitude, 347 degrees east longitude. The image is of an area 28 kilometers (17 miles) wide and 75 km (46 miles) long. This region is at the intersection of two tectonic trends. An extensive set of east-west trending fractures extends to the west (left) and a second set extends down to the south-southeast (lower right). The lines of pits suggest some igneous or volcanic activity accompanying the faulting.

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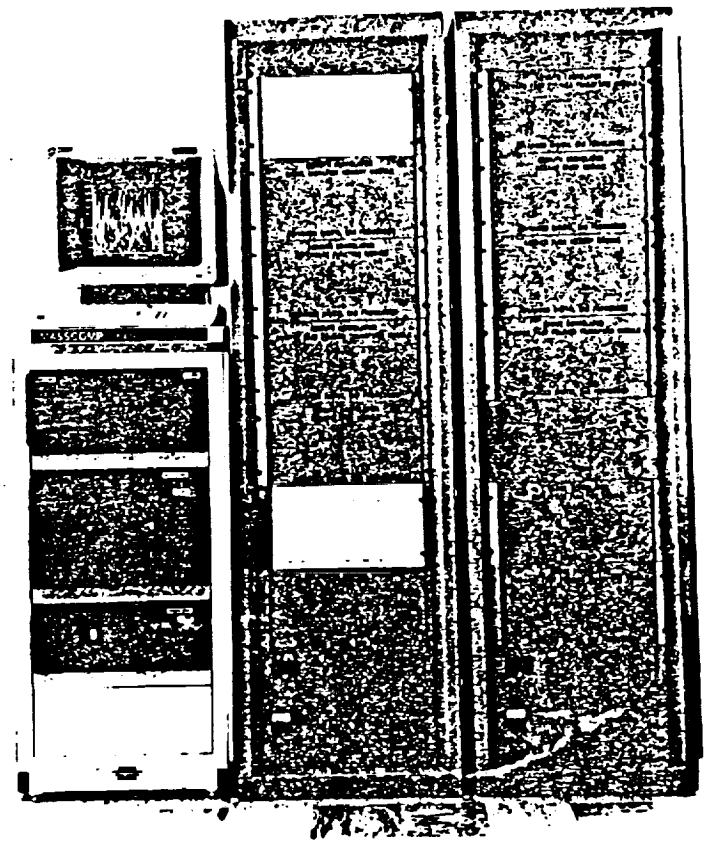
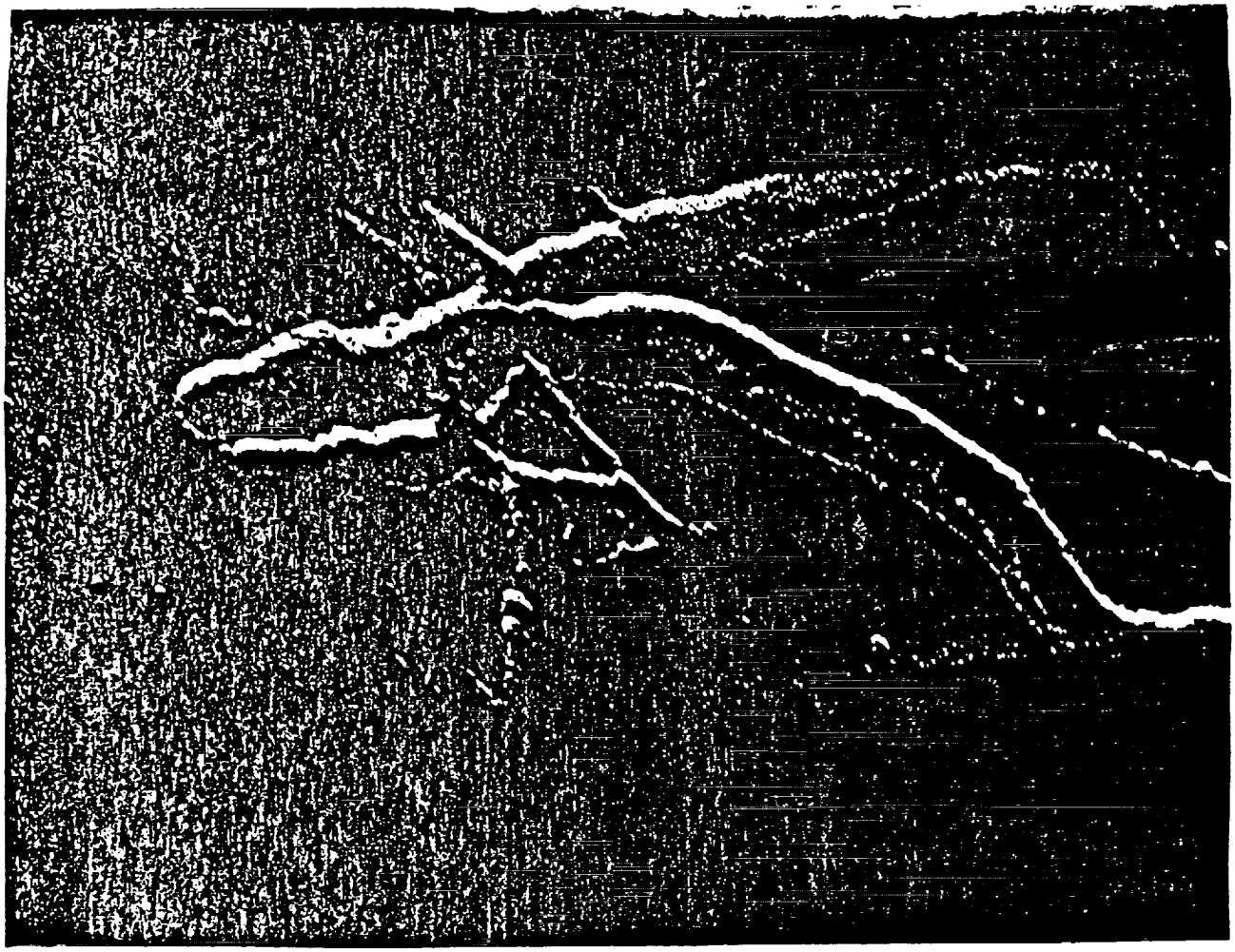
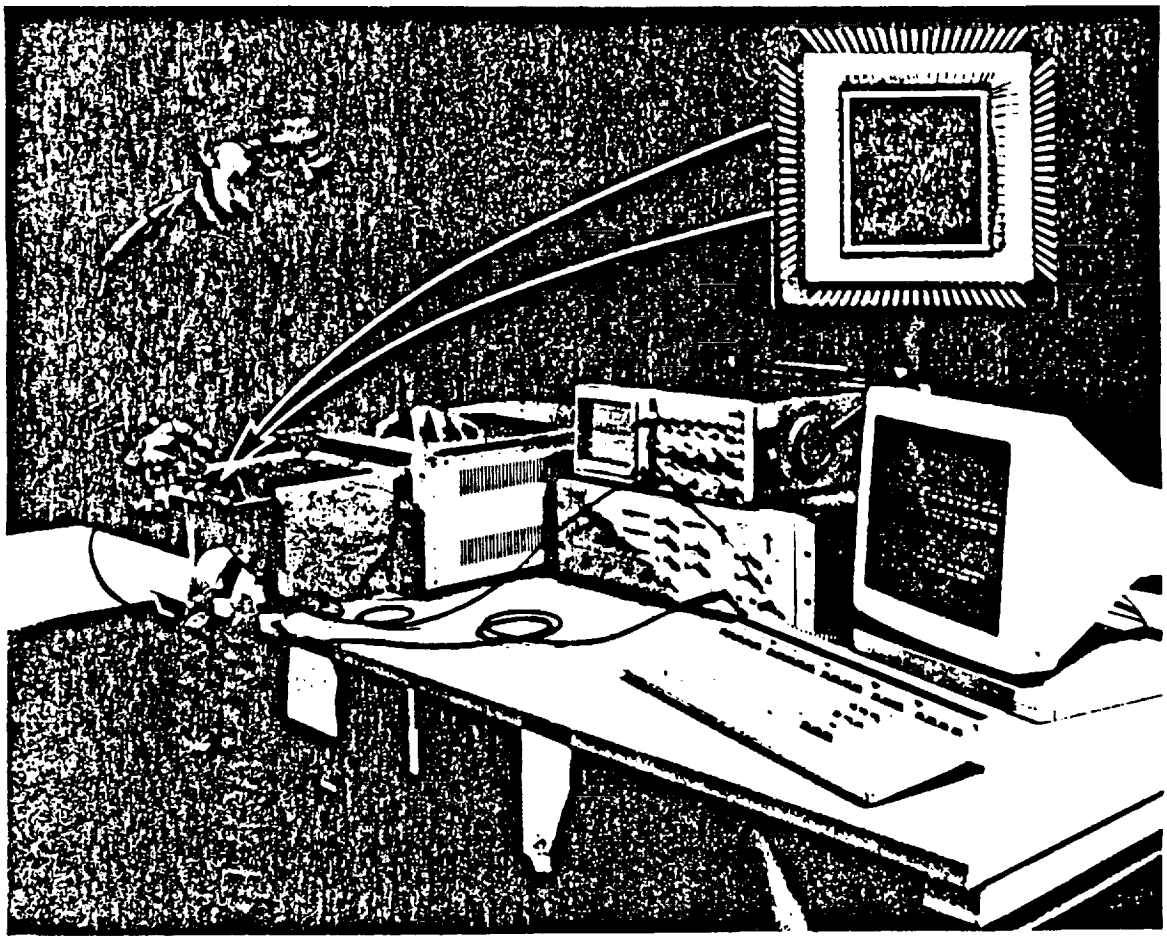


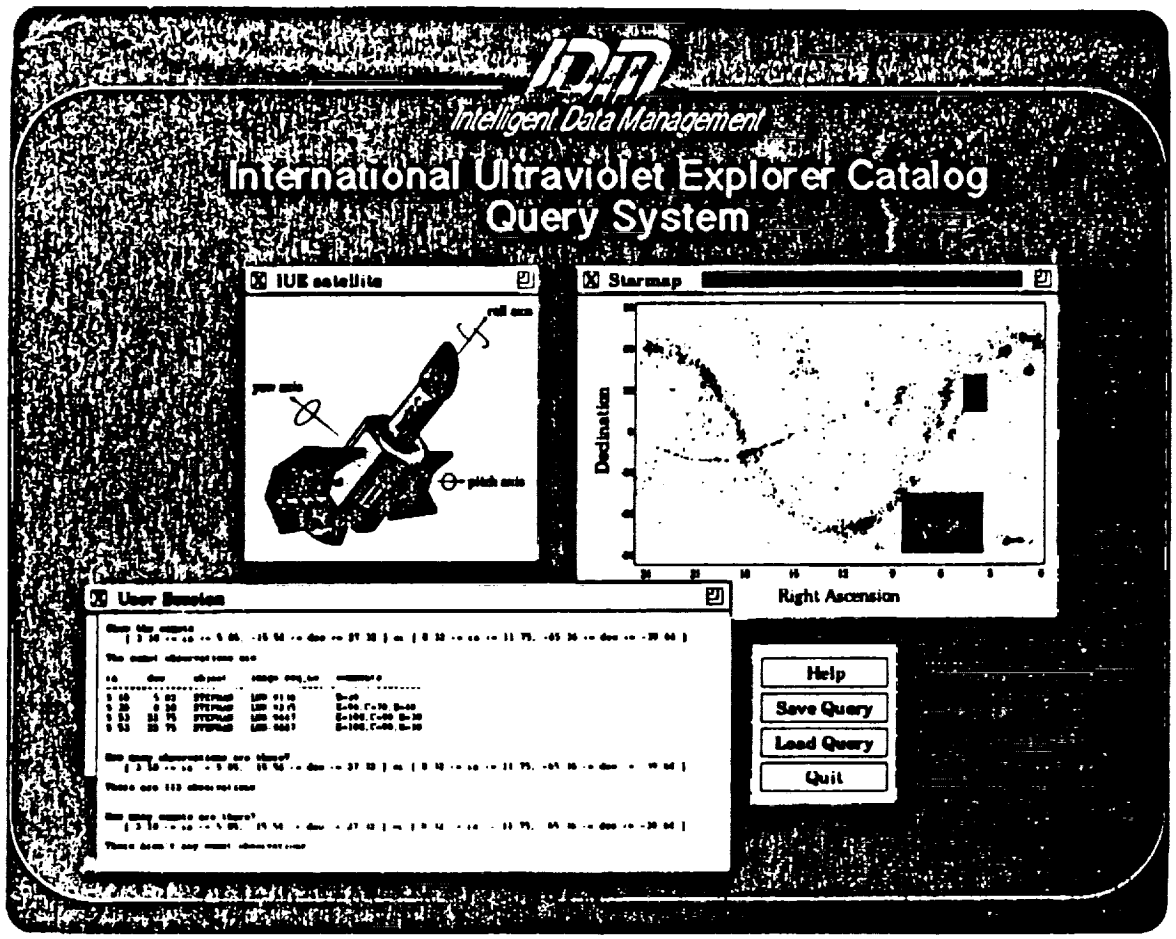


ISFLIP

DSCS — DATA SYSTEMS & COMPUTER SCIENCE



IDM

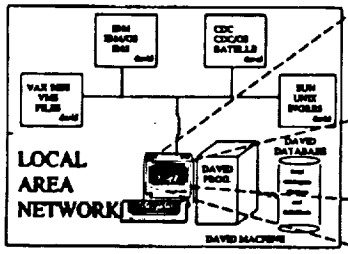


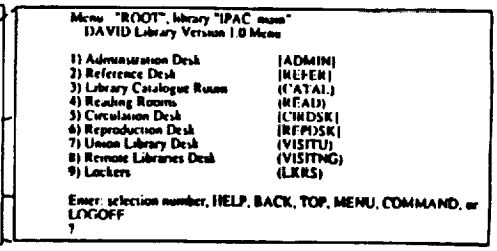
DAVID

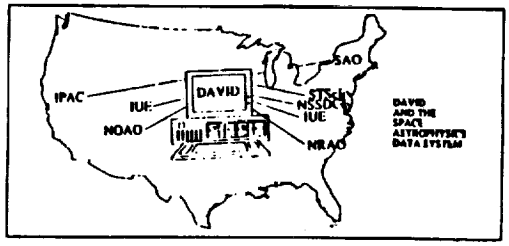
DSCS — DATA SYSTEMS & COMPUTER SCIENCE

Distributed Access View Integrated Data Base (DAVID)

PROBLEM: • NASA SCIENTISTS AND ADMINISTRATORS HAVE TO LEARN MANY DIFFERENT SYSTEMS AND ACCESS METHODS IN ORDER TO OBTAIN DATA.







ACCOMPLISHMENTS

- BUILT AND TESTED VERSION 1 OF "MAIN ROOM" SOFTWARE FOR THE "LIBRARY LAYER" ON TOP OF THE DAVID ENGINE.
- BUILT AND TESTED VERSION 1 OF THE "READING ROOM" SOFTWARE FOR THE "LIBRARY LAYER" ON TOP OF THE DAVID ENGINE.
- INSTALLED DAVID SOFTWARE AT ASTROPHYSICS DATA CENTERS- IPAC, SAO, IUE, NRAO, NOAO, STScI & NSSDC.

CURRENT WORK

- WORK WITH ASTROPHYSICS DIVISION (CODE EZ) ON BUILDING A DISTRIBUTED DATA SYSTEM USING DAVID AS A VEHICLE FOR ACCESSING DATA.
- MAKE IMPROVEMENTS TO DAVID ENGINE/ LIBRARY LAYER BASED ON LESSONS LEARNED.

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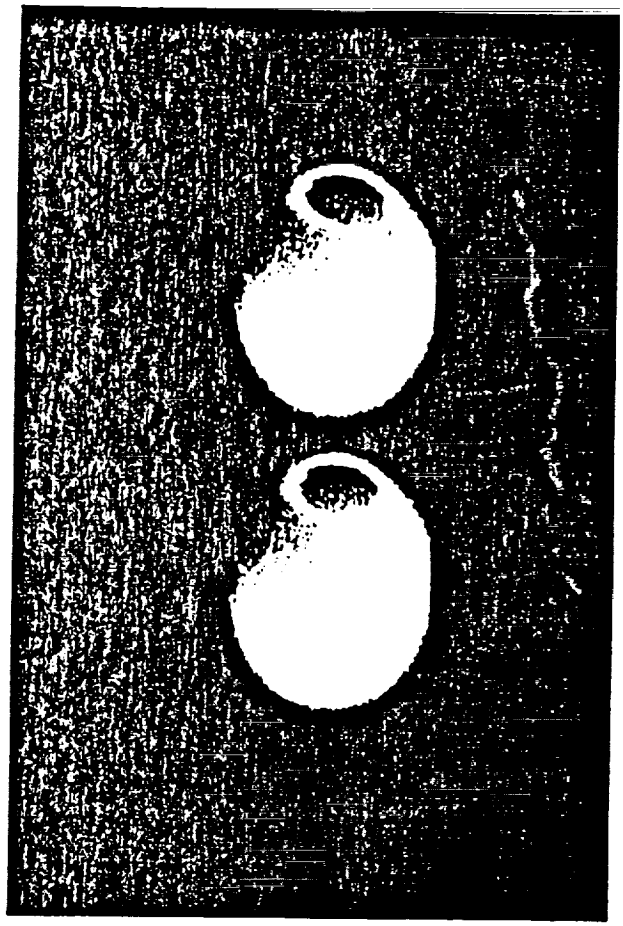
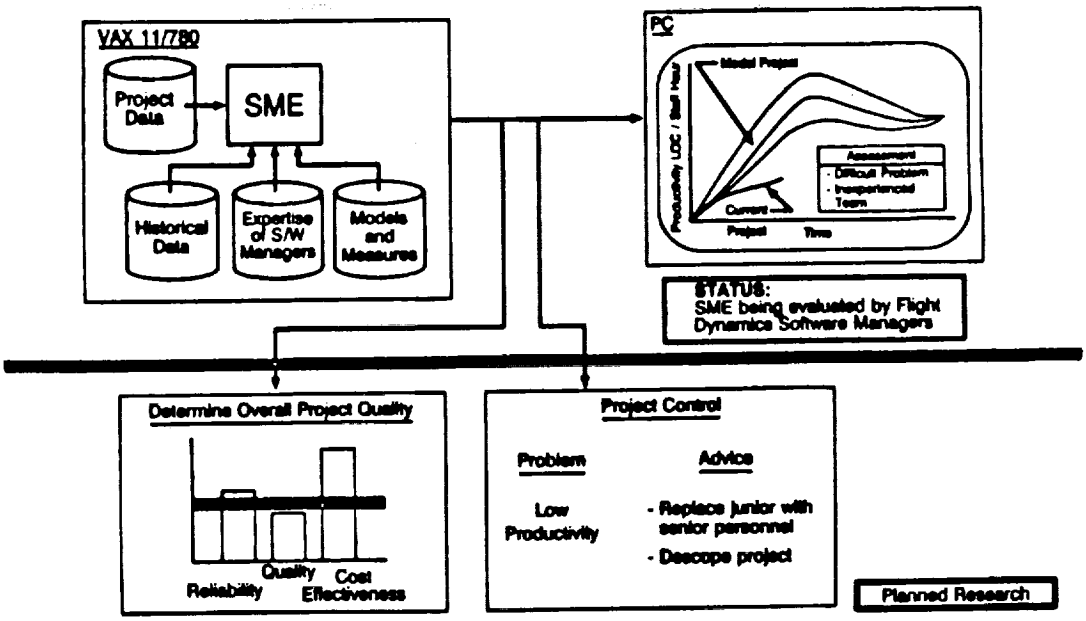
Auroral Oval: Automatic Analysis

DSCS — DATA SYSTEMS & COMPUTER SCIENCE



SME



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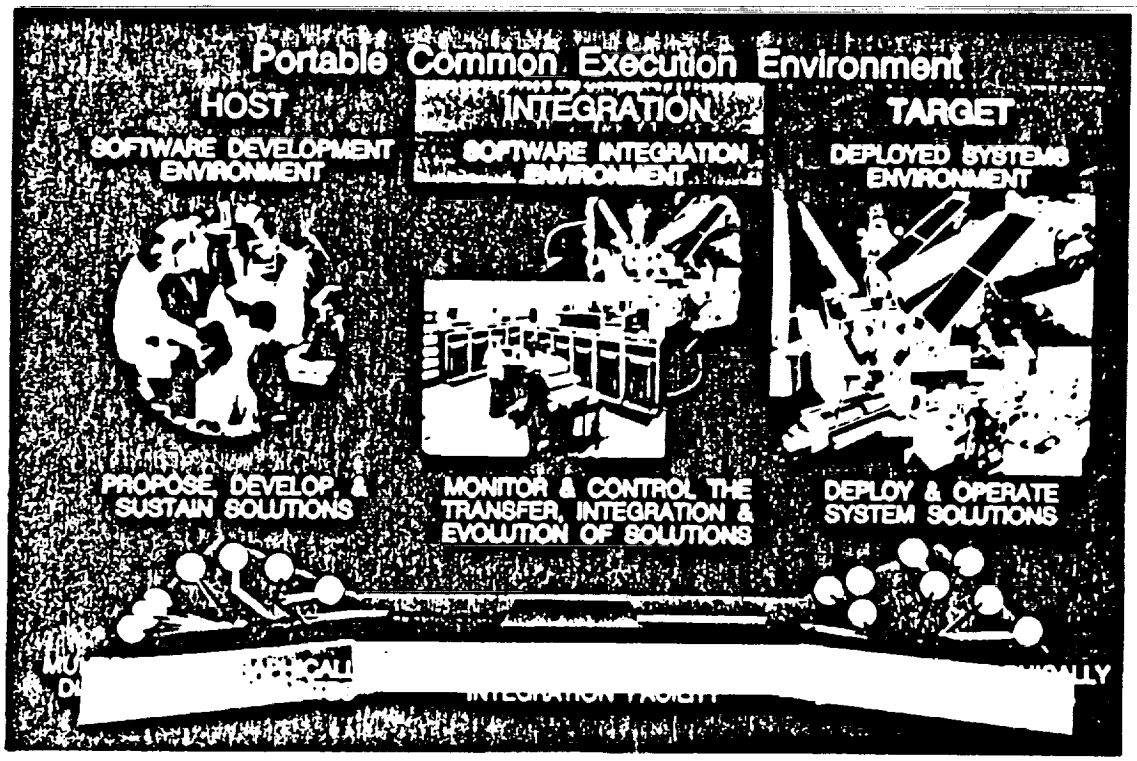
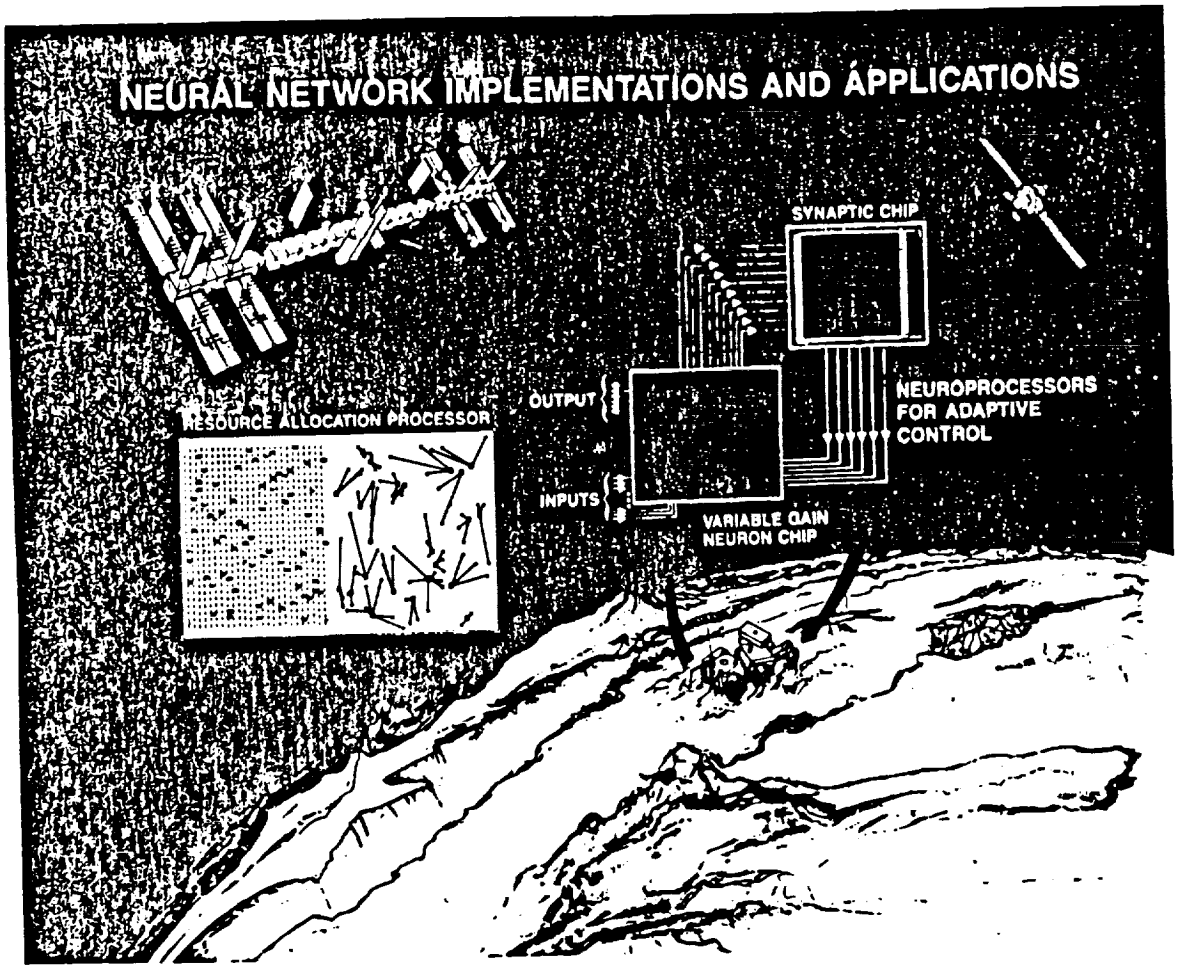
S/W ENGINEERING RESEARCH CENTER

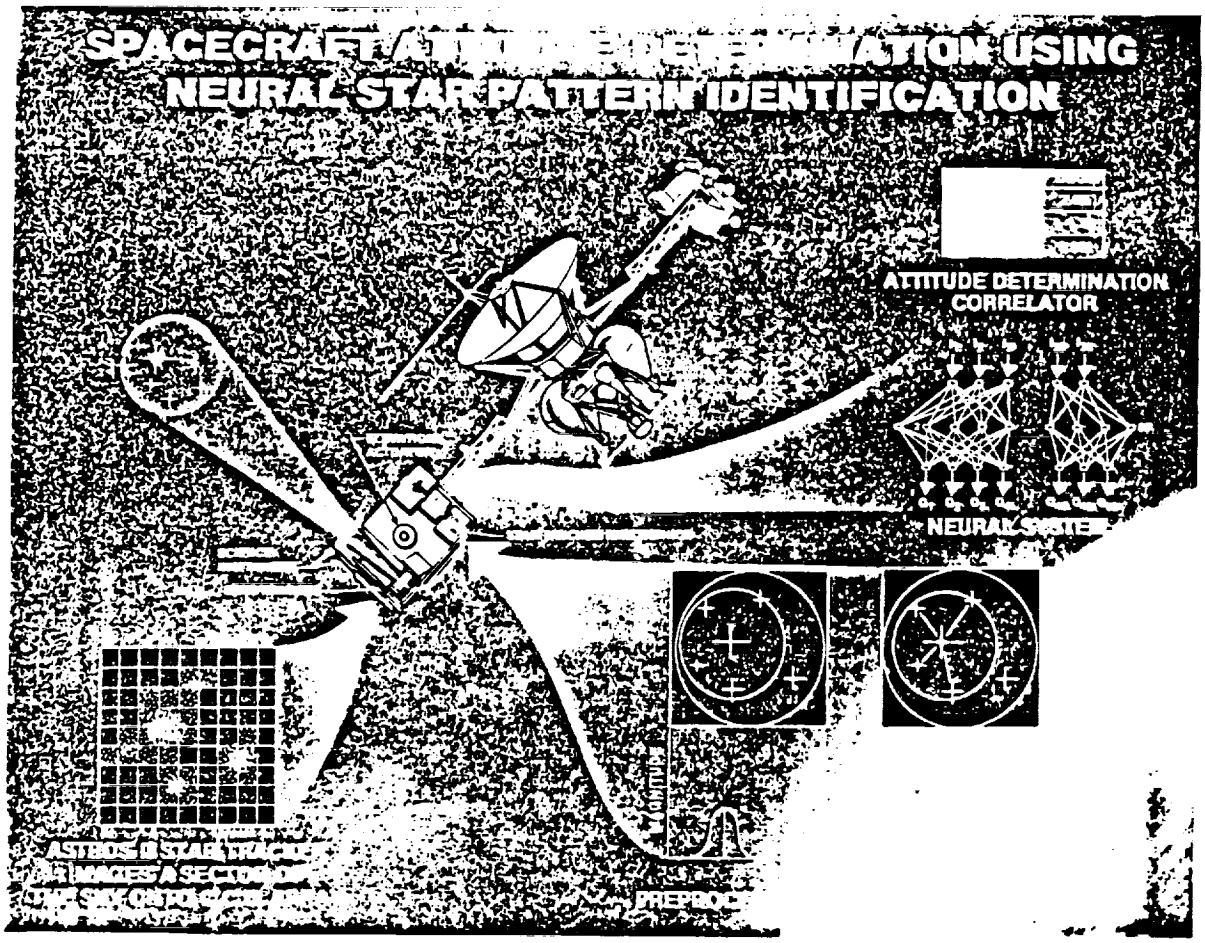
DSCS — *DATA SYSTEMS & COMPUTER SCIENCE*



NEURAL SYNAPTIC ARRAY CHIP

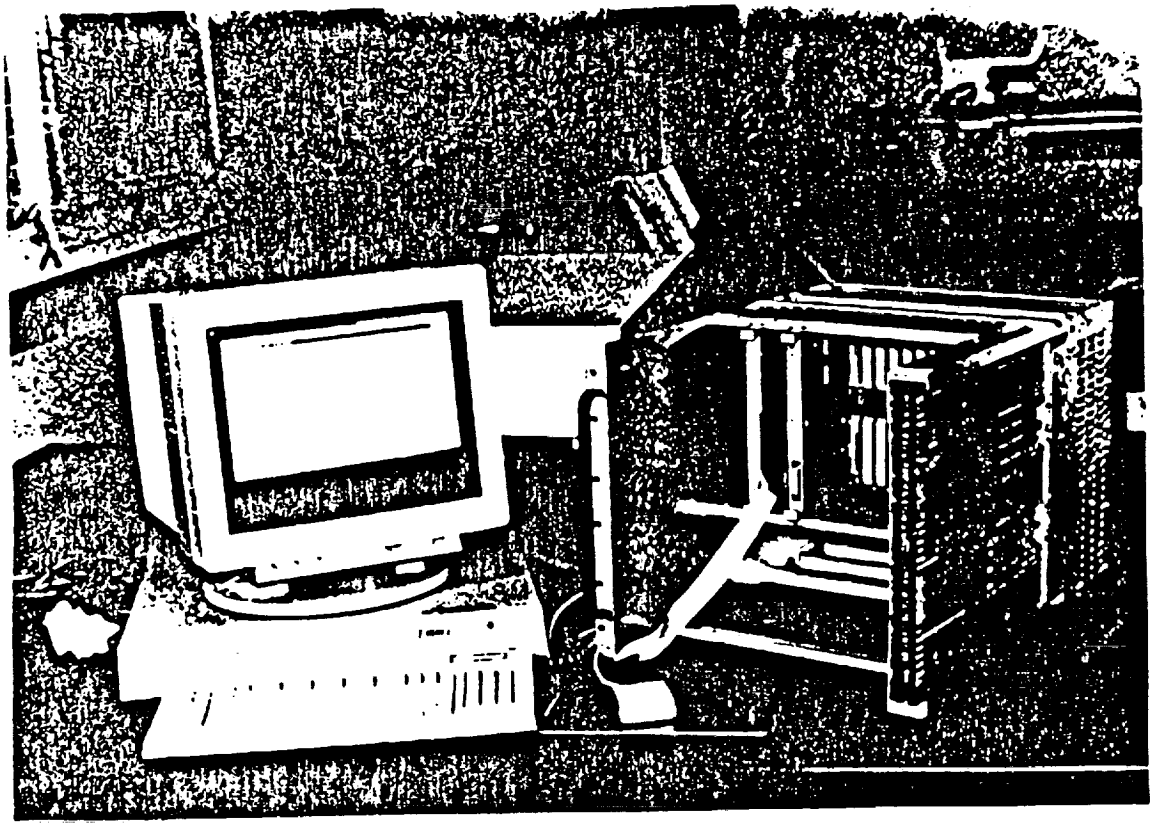


NEURAL STAR TRACKER



SDM

DSCS — *DATA SYSTEMS & COMPUTER SCIENCE*



ESC, or Encyclopedia of Software Components

TASK DESCRIPTION:

- a hypermedia software cataloguing and retrieving system
- an electronic metaphor of an encyclopedia
- organizes software into a dynamic, linked knowledge structure
- multiple access modalities
  - goal-directed searching
  - browsing with hyperlink tracing
- distributed contents
- contents in many programming languages and of many levels of granularity
- contents of many forms: code, documentation, graphics, etc.
- Encyclopedia Construction Kit supports user contributions and specialized handbooks

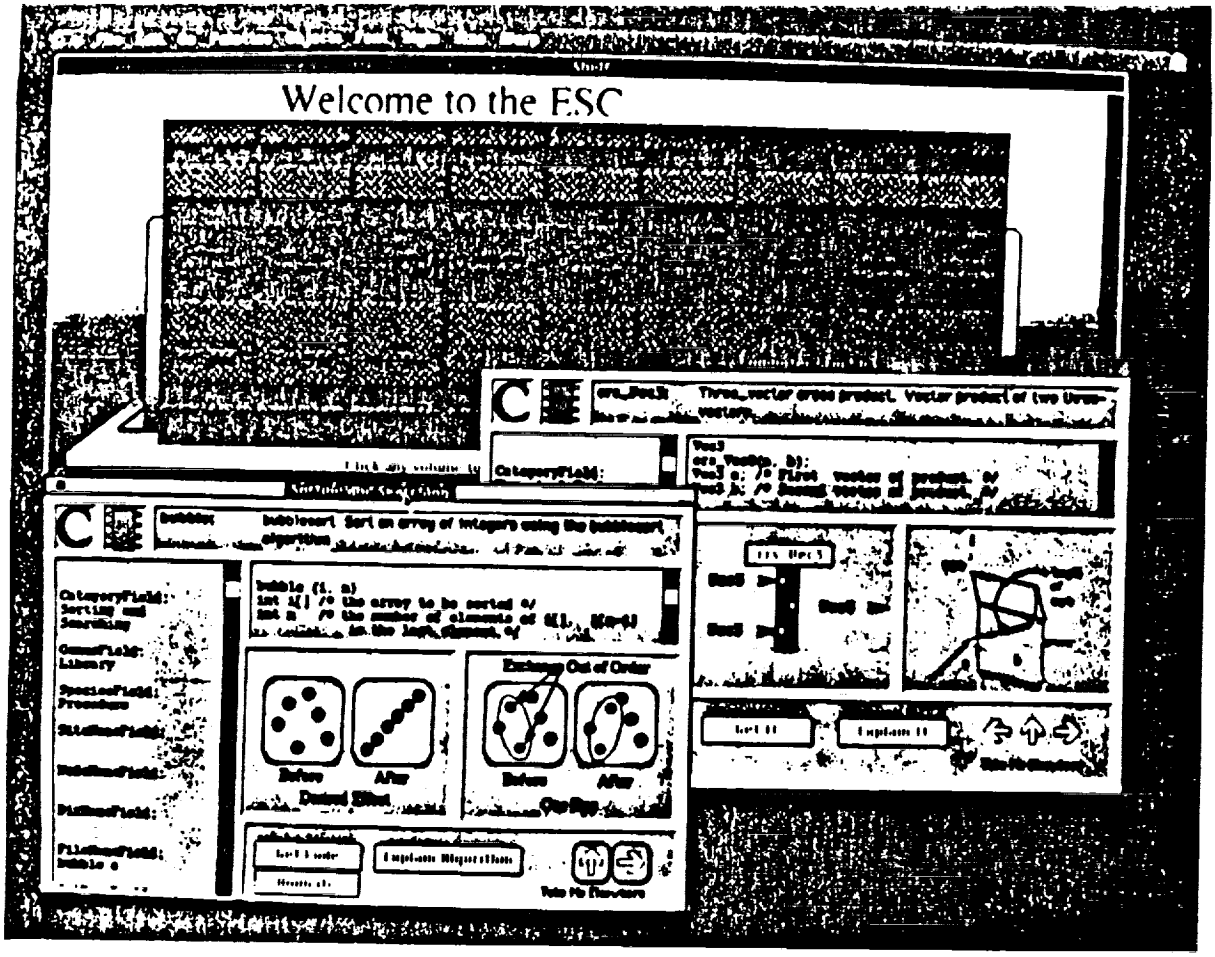
NASA NEED AND SIGNIFICANCE:

- an interchangeable software parts technology is greatly needed
  - such a technology has existed for hardware for over a century
- reuse will not be widespread until it is easier and cheaper to find software than to write it anew

CURRENT STATUS:

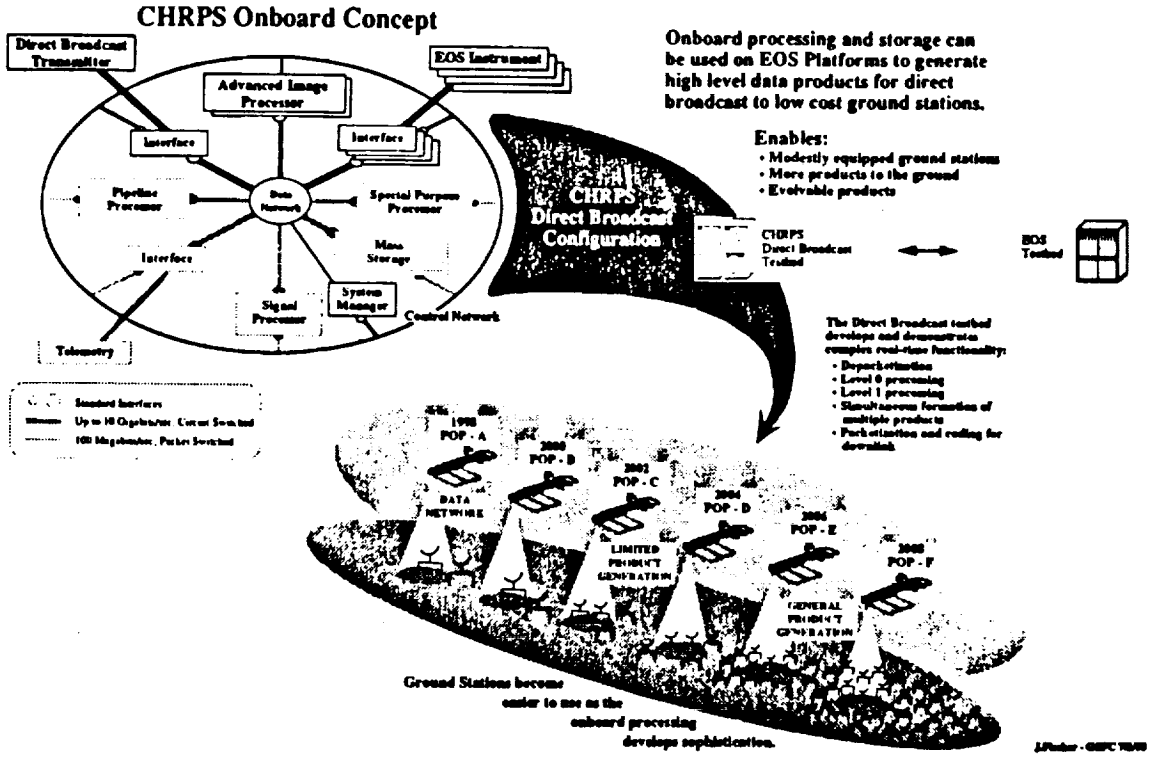
- conceptual prototype: June 1990
- prototype runs on color Macintosh systems
- Activities for 1991
  - collect feedback on interface and contents
  - update the conceptual prototype
  - engineer insertion and retrieval mechanisms
  - conduct preliminary investigation of roles of AI (artificial intelligence)

Technical contact: Dr. Brian Beckman, JPL, (818) 354-1252

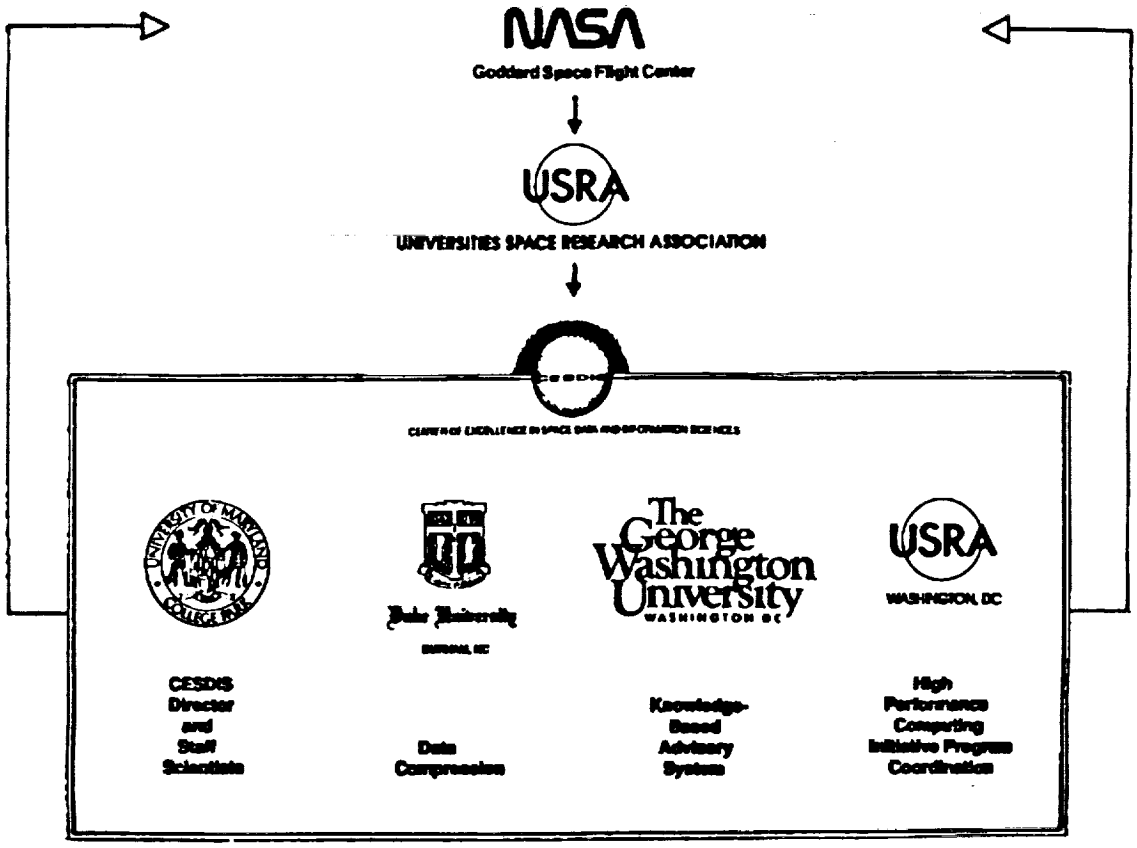


CHRPS

DSCS — DATA SYSTEMS & COMPUTER SCIENCE


CHRPS Onboard Concept
Direct Broadcast Transmitter
Advanced Image Processor
EOS Instrument
Interface
Interface
Pipeline Processor
Data Network
Special Purpose Processor
Mass Storage
Interface
Signal Processor
System Manager
Control Network
Telemetry
Onboard processing and storage can be used on EOS Platforms to generate high level data products for direct broadcast to low cost ground stations.
Enables:
• Modestly equipped ground stations
• More products to the ground
• Evolvable products
CHRPS Direct Broadcast Configuration
CHRPS Direct Broadcast Testbed
EOS Testbed
The Direct Broadcast testbed develops and demonstrates complex real-time functionality:
• Depacketization
• Level 0 processing
• Level 1 processing
• Simultaneous formation of multiple products
• Packetization and coding for downlink
1998 POP - A
2000 POP - B
2002 POP - C
2004 POP - D
2006 POP - E
2008 POP - F
DATA NETWORK
LIMITED PRODUCT GENERATION
GENERAL PRODUCT GENERATION
Ground Stations become easier to use as the onboard processing develops sophistication.

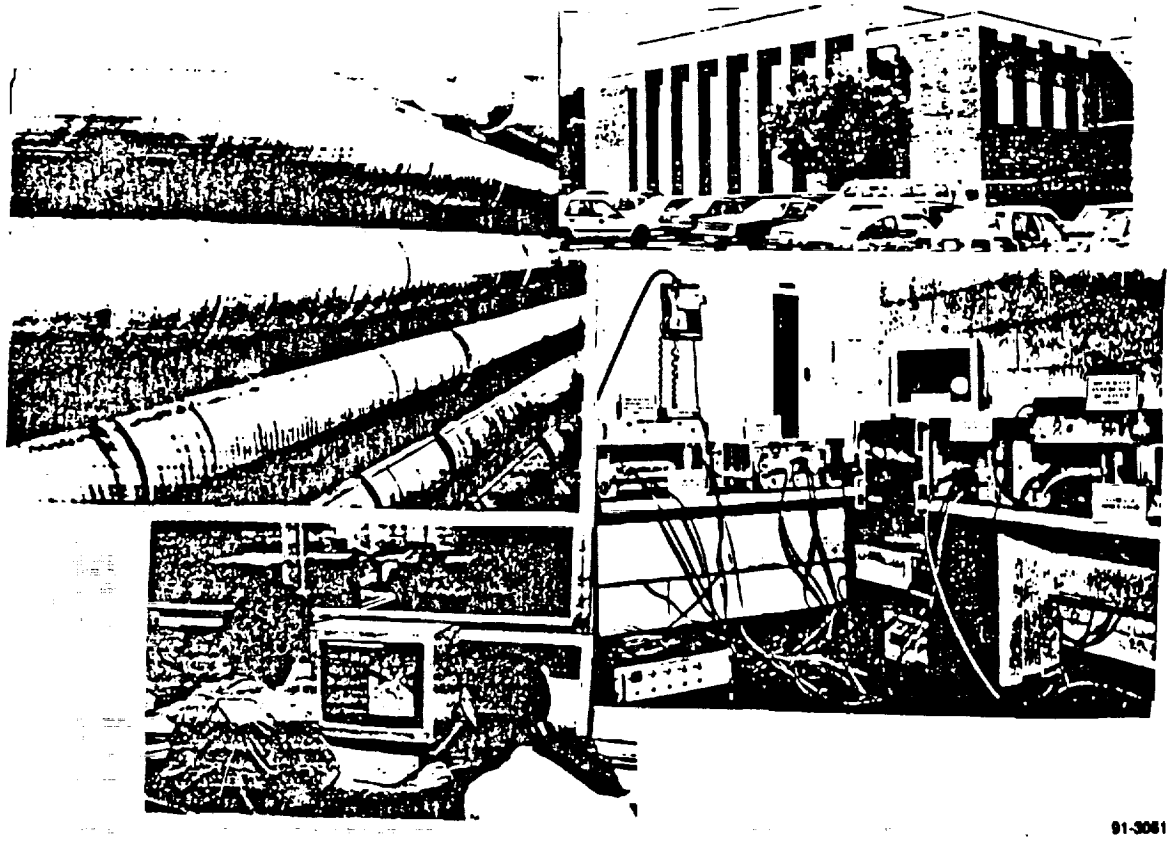
NASA/UNIVERSITY COLLABORATION THROUGH CESDIS



FACILITIES (GSFC)

DSCS — *DATA SYSTEMS & COMPUTER SCIENCE*

Goddard Space Flight Center



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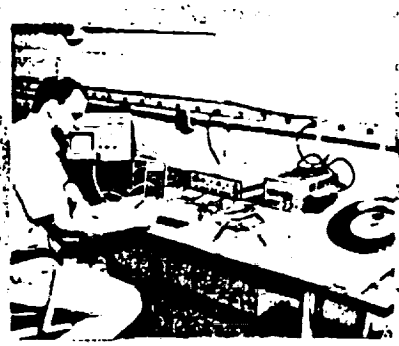
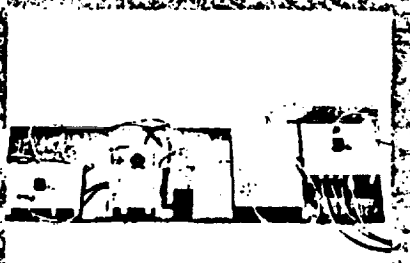
FACILITIES (LaRC)

SPACE DATA SYSTEMS
LANGLEY RESEARCH CENTER

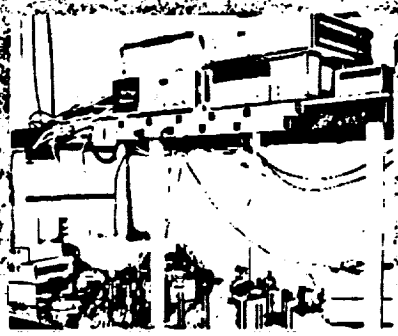
VHSIC MULTIPROCESSOR



SODR CONTROLLER



MFOX



SODR LASER ARRAY

PRODUCTS / DELIVERABLES: ONGOING

DSCS — *DATA SYSTEMS & COMPUTER SCIENCE*

FY 93-97

- Develop and demonstrate spacecraft computer technologies which operate in a heterogeneous environment and increase data transport capabilities:
  - Multiprocessor architecture and operating system (1993-1997)
  - Reconfigurable front-end pipeline processor using GaAs technology (1993-1995)
  - Solid state recorder using vertical block line (VBL) storage devices (1994-1997)
  - Configurable High-Rate Processor System (CHRPS) network using space-qualifiable components (1993-1997)
  - Develop MFOX Tx/Rx onboard network components; 5-10 Gb/s Prototype (1993-1995)
  - Testbed for onboard data systems available for project evaluation (1993-1997)

(Continued next page)

PRODUCTS / DELIVERABLES: ONGOING

DSCS — (continued) — DATA SYSTEMS & COMPUTER SCIENCE

FY 93-97

- Develop and demonstrate archiving, retrieval, visualization, and analysis techniques for very large, complex scientific data sets:
  - Application of sparse distributed memory to Earth science data sets (1992)
  - Management system for access to heterogeneous software tools (1993)
  - New technologies for spatial and spectral feature recognition (1994)
  - Statistical methods for analyzing very large data sets (1995)
  - Natural language query translation to object-oriented database (1996)
- Develop programming techniques designed to decrease cost and schedule risk of software development:
  - Mission and safety-critical software operating system kernel validated (FY93)
  - Portable, fully functional Encyclopedia of Software Components (ESC) (FY93)
  - Knowledge-base approach to software architecture reuse (FY95)

PROGRAM STRUCTURE

DATA — "STRATEGIC PLAN" — DATA SYSTEMS & COMPUTER SCIENCE

UNIVERSITY PROGRAMS	BASE R&T COMPUTER SCIENCE	FOCUSED PROGRAMS	PRESENTATIONS
VLSI CENTER AT U. OF IDAHO		SPACE DATA SYSTEMS	SPACE DATA SYSTEMS • Onboard Memory & Storage • Advanced Flight Computers • Special Purpose Flight Processors • Onboard Networking & Testbeds
CASIS AT STANFORD	INFORMATION MANAGEMENT	SCIENCE INFORMATION	SCIENCE INFORMATION SYSTEMS • Archive, Access, & Retrieval • Visualization
	NEURAL NETS		NEURAL NETWORKS
RICIS AT THE U. OF HOUSTON, CLEARLAKE	SOFTWARE ENGINEERING	SOFTWARE FOR OPERATIONS SUPPORT	SOFTWARE ENGINEERING
		FLIGHT CONTROL & OPERATIONS	FLIGHT CONTROL & OPERATIONS

STRATEGIC PLAN: Technology Challenges

DSCS — DATA SYSTEMS & COMPUTER SCIENCE

TECHNOLOGY AREA	STATE-OF-THE-ART	TARGETS
Space Data Sys. Memory & Storage	**Longitudinal Tape** Capacity: $7.7X10^{10}$ bits; Sequential; Rate: $8.5x10^{7}$ bps; Weight: 155 lbs; Status: Space-Qualified **Rotary Head** Capacity: $1.0x10^{12}$ bits; Sequential; Rate: $3x10^{8}$ bps; Weight: 76 lbs; Status: Under Development **Nonvolatile RAM** Core Memory (Zero Power NVRAM)	**Optical Disk (SODR)** Capacity: $8X10^{10}$ bits; Random; Rate: $3x10^{8}$ bps; Weight: 60 lbs; Status: Level 5 1995 **Solid State Recorder (SSR)** Capacity: 10^{9} bits; Random: Rate: $3x10^{6}$; Weight: 3 lbs; Status: Demo 1997 **Nonvolatile RAM** 4 Mbit NVRAM Chips Demo 1997
Flight Computers	(1802) Rad-hard, SEU immune Rate: 100 KIPS; 5 W/MIPS; Status: Flown (1750) Rad-hard, SEU immune Rate: 2-4 MIPS; 2 W/MIPS; Status: Level 5	Rad-hard, SEU-immune, 32 bit Computer Rate: 3-15 MIPS; 0.5-1.0 W/MIPS

(Continued next page)

STRATEGIC PLAN: Technology Challenges

(continued)

DSCS — DATA SYSTEMS & COMPUTER SCIENCE

TECHNOLOGY AREA	STATE-OF-THE-ART	TARGETS
Special Purpose Processors	Imaging Spectrometry Parameter Extraction - None Available **SAR Image Generation** 50 MBPS; 800 MOPS; 2.7 MOPS/WATT; Status Level 2+ **Autocorrelation** 128 MHz Bandwidth; 250 mW/Channel **Data compression** Lossless: 2-3 to 1; special cases in H/W Lossy: Software	EOS HIRIS CLASS 500 MFLOPS; 7MFLOPS / W **SAR Image Generation** 50 MB/S; 800 MFLOPS; 20 MFLOPS/WATT; Status Level 5 **Autocorrelation** 250 MHz Bandwidth; 20 mW/Channel **Data compression** - Hardware Lossless 2-3 to 1; Generic standard H/W Lossy Up to 100 to 1 Compression Ratio subject to data characteristics
Onboard Networks	(1553) 1Mbit/s; Wire (1773) 10 Mbit/s; Fiber (not flown) (FDDI/WDDI) 100 Mbit/s; Fiber/wire (not flown	Multi-gigabit/s; Fiber Optic
Science Information Systems	Most data archived off-line, organized by satellite instrument and time Visualization is non-interactive and non-real-time	Storage structure for content-based queries, automatic data labeling and characterization scalable to 10^{15} bytes/year Interactive, near-real-time visualization of large and complex data sets

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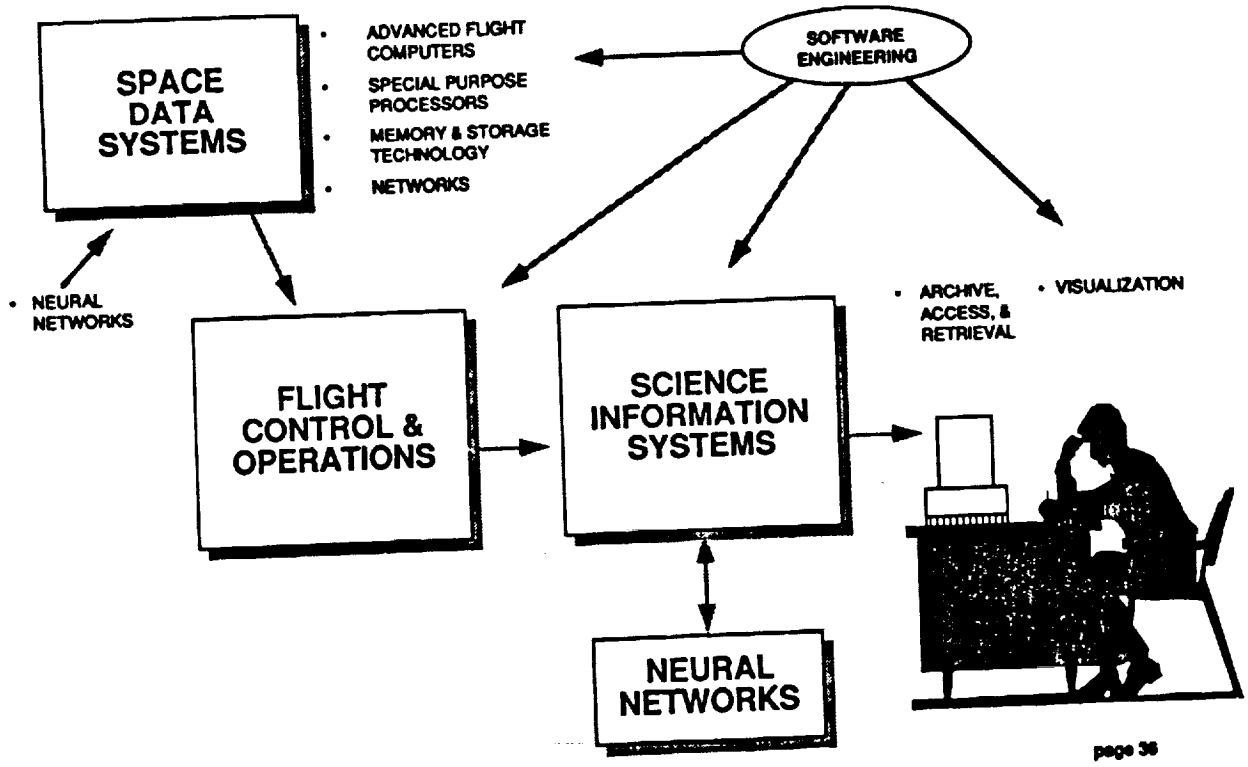
STRATEGIC PLAN: Technology Challenges

(continued)

TECHNOLOGY AREA	STATE-OF-THE-ART	TARGETS
Software Engineering	Ability to predict process and product performance and cost lags far behind hardware in part due to poor or unused process tools, standards, and methods	Improve NASA's ability to cost and risk-effectively develop, operate, and maintain complex, critical, and reliable software (Software represents 20% of NASA's budget)
Neural Nets	Mostly small-size, feed-forward networks; Spectral transforms; Neural net software for thruster/planetary lander control 256-neuron, 65 k synapse CCD/CID chips	Large-scale, self-organizing networks; Geophysical/aerodynamics modeling (PDEs); Data compression; Propulsion -only flight controller 1024-neuron, synchronous CCD/CID arrays with 14-16-bit processing precision
Flight Control & Operations	Loosely coupled networks of workstations, mini-computers, and mainframes; insufficient sequence generation for quick response.	Rapid sequence generation/validation demonstrated and validated using CRAF/Cassini data

DATA SYSTEMS & COMPUTER SCIENCE PROGRAM & TESTBED RELATIONSHIPS



RELATED PROGRAMS

DSCS — DATA SYSTEMS & COMPUTER SCIENCE

- DoD memory and storage programs which are not jointly funded do not meet NASA's needs
- SDIO is currently focussed on RH-32 Uniprocessor development for their Brilliant Pebbles program but is continuing to slip development schedules with budget decreases
- EOSDIS focusing on implementing state-of-the-art technology; opportunity for enhancing EOSDIS over the next 5-10 years can be met with techniques developed through the Science Information Systems program
- NASA Code QE software engineering plan and lifecycle standards; DoD (STARS and SEI), SPC, MCC, IEEE & ACM
- Small, independent neural net tasks supported by OSSA, OSF; DARPA, ONR, AFOSR; start-up companies
- Flight integration system technology; Similar concepts being explored in DoD, DoE, and industry

RELATED PROGRAMS

DSCS — (facing page3) — DATA SYSTEMS & COMPUTER SCIENCE

RELATED EFFORTS: Space Data Systems—Flight Computer

- Participate in CAP-16, GVSC / ASCM, RH-32 / ATIM programs and reviews
- Cofunded multiprocessor application with SDIO
- Coordinated with SDIO through PMA-TIM's, AF-Phillips Lab, AF-Rome Lab, USE-SDC Huntsville, USN-NRL
- Coordinated with DARPA / ISTO in evaluation of parallel and distributed processors (IWARP, Multimax, Gigamax)
- Coordinated with AF through STIP sub-panel with opportunity for co-development on the RH-32 (Air Force initiative to replace loss from SDIO)
- Coordinated with HPCC-REE elements in Advanced Multicomputer Architecture for Spacecraft Applications

RELATED EFFORTS: Space Data Systems—Special Purpose Processors

- Build on special purpose processors and digital signal processor developed for DoD applications
- Flight qualifiable prototypes demonstrate technology readiness for NASA and DoD instruments
- Support the use of DoD developed Qualified Manufacturing Lines (QML)
- Exploit microelectronics technologies developed for commercial and government use

RELATED EFFORTS: Space Data Systems—Networks and Testbeds

- EOS testbed tested in a direct derivative of the CHRPS Testbed and is being coordinated with CSTI Testbed activities
- DARPA is supporting the development of high data rate network components
- AMES Research Center is developing a networking testbed with DARPA funding

(Continued next page)

RELATED PROGRAMS

(facing page 5)

RELATED EFFORTS: Science Information Systems — General

- DOE
  Using artificial neural networks to determine genetic DNA folding and logical pairing of genes (genome project)

  Expert systems used to monitor nuclear power plant operations and maintenance, health and safety.

  Dynamic system for arm race model in determining and tracking costs and long-term implications of various policy making decisions.

- DoD
  Many applications in AI for advancing weaponry and satellite information gathering, most of which is highly classified.

  CIA uses AI for text retrieval and speech recognition; Pentagon uses various AI techniques for war gaming and weapon simulations; Coast Guard uses AI for control of illegal shipping; AI also used in communications analysis and signal processing in electronic warfare.

- FAA
  AI used to identify incoming aircraft traffic and help controllers make better decisions.

- NIH
  Knowledge-base system used to determine probable malignancy and cancerous genes.

- NOAA
  Expert systems for automating geodetic cartography

PROGRAM STRUCTURE

"3x BUDGET PLAN"

UNIVERSITY PROGRAMS	BASE R&T COMPUTER SCIENCE	FOCUSED PROGRAMS	PRESENTATIONS
VLSI CENTER AT U. OF IDAHO		SPACE DATA SYSTEMS	*SPACE DATA SYSTEMS* • *Onboard Memory & Storage* • *Advanced Flight Computers* • *Special Purpose Flight Processors* • *Onboard Networking & Testbeds*
CASIS AT STANFORD	INFORMATION MANAGEMENT	SCIENCE INFORMATION	*SCIENCE INFORMATION SYSTEMS* • *Archive, Access, & Retrieval* • *Visualization*
	NEURAL NETS		*NEURAL NETWORKS*
RICIS AT THE U. OF HOUSTON AT CLEARLAKE	SOFTWARE ENGINEERING	SOFTWARE FOR OPERATIONS SUPPORT	*SOFTWARE ENGINEERING*
		FLIGHT CONTROL & OPERATIONS	*FLIGHT CONTROL & OPERATIONS*

3X IMPACT KEY
UNAFFECTED
REDUCED
ELIMINATED

PRODUCTS / DELIVERABLES: 3x BUDGET PLAN

FY93 - 97

- Products and deliverables from ongoing program
- Demonstrate Rad-hard, SEU-immune 32-bit computer; and apply the Advanced Image Processor architecture to SAR and Multispectral imaging instruments.
- Develop and demonstrate components and subsystem for Spaceflight Optical Disk Recorder (SODR) and NVRAM technology
- Demonstrate rapid archiving, near-real-time browse, content-based query, and the ability to navigate very large, complex scientific data sets in near-real-time
- Develop methodology for quantifying SW reliability and formal methods for building safe software systems (1996)
- Develop a spectral neural processor for onboard science signal processing (1994), a neural processor for onboard science data reduction at Gbits/sec (1995), and a neural processor for dynamic resource allocation and health monitoring (1997)

PRODUCTS / DELIVERABLES: STRATEGIC PLAN

FY93 - 97

- Products and deliverables for 3x Budget Plan
- Develop and demonstrate reliable, low-power, high-speed, spacecraft data network elements
- Demonstrate automatic anomaly detection
- Domain analysis of representative NASA SW applications (1994)
- Neural controller for guidance/landing planetary landers (1996)
- Initial multi-mission operations center test-bed operational (1994); Rapid sequence generation/validation demonstrated (1996); CRAF/CASSINI validation of operational concept (1997)

EFFECT OF STRATEGIC VS. 3x BUDGET

- Eliminate focused software development for Operations
- Stretch Advanced Flight Computer development by 2 years
- Delay start of Solid-State Memory (VBL) by 2-3 years
- Reduce microelectronic technology to a less robust program
- Curtail applications-focused neural network technology
  or
  Replan and reduce neural network basic research by 50%
- Curtail integration and vailidation testbed for new architectures
- Eliminate Flight Control and Operations technology

KEY ISSUES

- Risk in total reliance on DoD for production of space-qualified data system components
  - — Shrinking defense budgets
  - — DoD focuses on own needs first
- Without a clear up-front demonstration of the maturity and applicability of advanced technology to reduce program risk, future missions will be very slow to introduce such advances into critical areas such as onboad systems and operations centers
- Opportunity to enhance EOSDIS data management capacity for archiving and analysis if funding, development, and technology transfer activities proceed in a timely manner
- Dropping the focused software engineering program will significantly lower the payoff and retard technology transfer from the Base R&T software program

SUMMARY

- Program is highly responsive to recommendations and customer needs
- Program is integral part of technology plan recommended by Augustine Report
- Balanced focused and base R&T program in the Strategic Plan augmentation
- Enable greater Science return from future space, Earth, and robotic Exploration missions
  - — Advanced Space Data Systems
  - — Neural Networks
  - — Flight Control and Operations
- Enable Scientific exploration of massive data bases (*e.g.*, EOS)
  - — Archive and content-based retrieval
  - — Visualization
- Control increasing cost to NASA of large, highly reliable software systems

SSTAC Review of the
Integrated Technology Plan for the Civil Space Program

DATA SYSTEMS & COMPUTER SCIENCE
SPACE DATA SYSTEMS

ONBOARD MEMORY & STORAGE

TOM SHULL

June 26, 1991

Langley Research Center

MEMORY & STORAGE

TECHNICAL OBJECTIVES

Develop high-performance, space-qualifiable, onboard computing, storage, and networking technologies

Memory & Storage Objective

Develop reliable, high performance memory and random block access storage components and system elements

- **Spaceflight demonstration of high performance, rewriteable optical disk Drive technology (SODR)**
- **Laboratory demonstration of scalable, low power solid-state recorder (SSR) based on vertical Bloch line (VBL) storage device**
- **Laboratory demonstration of fast, high density nonvolatile random access memory (NVRAM) chip**

JUSTIFICATION

- High performance data storage is high priority to user community
- NASA leading development of flight qualifiable block access storage and NVRAM memory
- High performance block access (mass) storage addresses growing data collection and processing requirements
  - — Optical disk (demonstrated) and vertical Bloch line (new) offer inherent reliability
  - — Random access offers enhanced capability / versatility
- High performance, nonvolatile RAM provide reliable / flexible program and data storage
- America can become a leader in high performance storage technology
  - — Great potential for ground application spin-off

TECHNOLOGY CHALLENGES

- Flight demonstration of high rate / capacity optical disk Drive
  - — Diode laser source & associated optical system reliability
  - — System design & packaging for flight environment
- Develop multi-Drive, multi-port, expandable system Controller
  - — Multi-Drive synchronization and simultaneous buffered I/O
  - — Configurable system architecture and control algorithms
- Develop vertical Bloch line storage device (new technology)
- Develop flight qualifiable nonvolatile random access memory cell (new technology)

STATE-OF-THE-ART ASSESSMENT

- Longitudinal recording on magnetic tape is state-of-the-art in qualified high capacity storage
  - — Rotary head / systems under development
  - — Small optical disk Drives being qualified
  - — SRAM solid-state recorders under development
- Core memory is state-of-the-art in qualified NVRAM
  - — Users need higher performance / density
  - — DoD development objectives differ from NASA's needs

STATE-OF-THE-ART ASSESSMENT

(facing page 1)

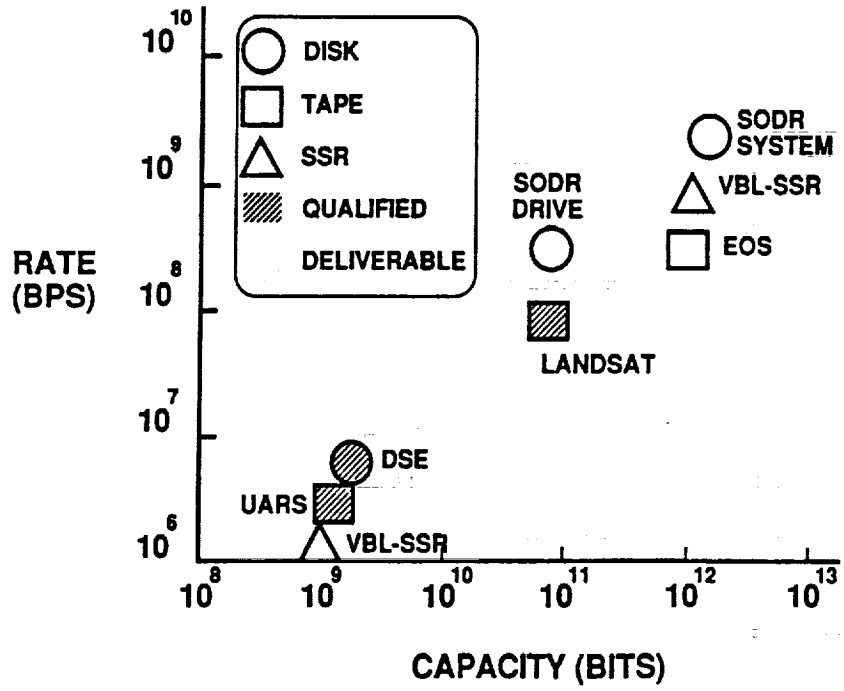
TYPE	UARS RECORDER LONGITUDINAL TAPE	LANDSAT VI RECORDER LONGITUDINAL TAPE	EOS RECORDER ROTARY HEAD TAPE	SODR DRIVE MAGNETO-OPTIC DISK
CAPACITY	$5X10^{8}$ BIT	$7.7X10^{10}$ BIT	$1.0X10^{12}$ BIT	$8.0X10^{10}$ BIT
DATA RATE	$3X10^{6}$ BPS	$8.5X10^{7}$ BPS	$3.0X10^{8}$ BPS	$3.0X10^{8}$ BPS
ACCESS	SEQUENTIAL (REVERSE)	SEQUENTIAL (REVERSE)	SEQUENTIAL (REWIND)	RANDOM (FIFO)
I/O	FIXED RATE (SELECTABLE)	?	4 RECORD RATES 1 PLAYBACK RATE	BUFFERED ASYNCHRONOUS
VOLUME	0.3 FT^3	5 FT^3	2 FT^3	1 FT^3
WEIGHT	14 LBS	155 LBS	76 LBS	60 LBS
POWER REC	19W	177W	192W	170W
PLAYBACK	10W	255W	189W	230W
STATUS	QUALIFIED	QUALIFIED NOT FLOWN	UNDER DEVELOPMENT	UNDER DEVELOPMENT
STRONG FEATURE	FLOWN	QUALIFIED	CAPACITY	RELIABILITY ACCESS
MFR	GE/RCA	ODETICS	GE	TBD

STATE-OF-THE-ART ASSESSMENT

(facing page 2)

TYPE	VBL-SSR SS RECORDER	VBL-SSR SS RECORDER	SRAM SOLID-STATE RECORDER	SRAM SOLID-STATE RECORDER
CAPACITY	10^9 BIT	10^{12} BIT	$3.6X10^9$ BIT	$8X10^{12}$ BIT
DATA RATE	10^6 BPS	$3X10^8$ BPS	10^6 BPS	10^9 BPS
ACCESS	RANDOM (BLOCK)	RANDOM (BLOCK)	RANDOM	RANDOM
I/O	?	?	?	?
VOLUME	0.01 FT^3	0.3 FT^3	0.05 FT^3	3 FT^3
WEIGHT	3 LBS	46 LBS	5 LBS	200 LBS
POWER REC	0.7W	36W	8W	1000W
PLAYBACK	0.7W	36W	8W	1000W
STATUS	UNDER DEVELOPMENT	FUTURE	UNDER DEVELOPMENT	PROPOSED
STRONG FEATURE	LOW POWER NONVOLATILE	LOW POWER NONVOLATILE	SOLID-STATE	SOLID-STATE
MFR	JPL	JPL	TI	TI

MASS STORAGE COMPARISON

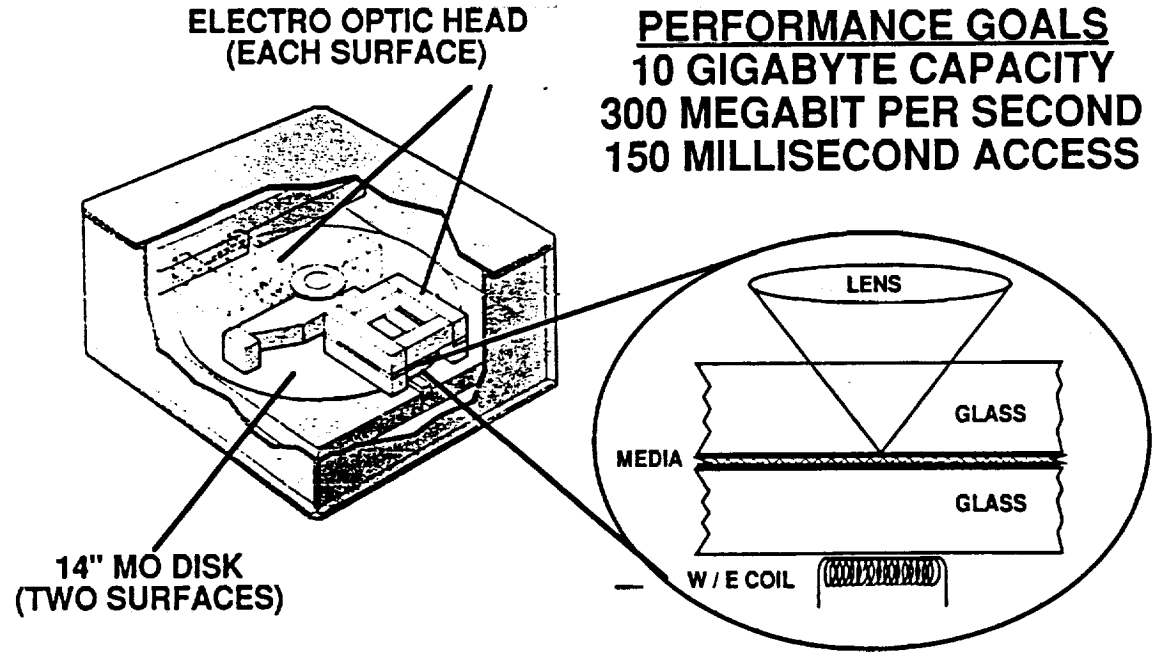


PROGRAM DESCRIPTION

SODR

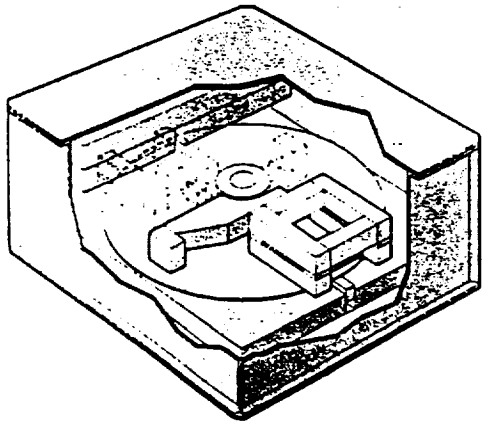
- Demonstrate high performance optical disk drive based on magneto-optic media
  - — High rate and capacity, 10E-12 bit error rate
  - — Random file access, first-in-first-out data playback
  - — Inherent reliability
- Demonstrate modular Controller which supports expandable system architecture
  - — Expands in rate, capacity, and data ports
  - — Buffered, variable rate data transfer
  - — Simultaneous read and write (multi-port)

SODR DRIVE CONCEPT



SODR OFFERS

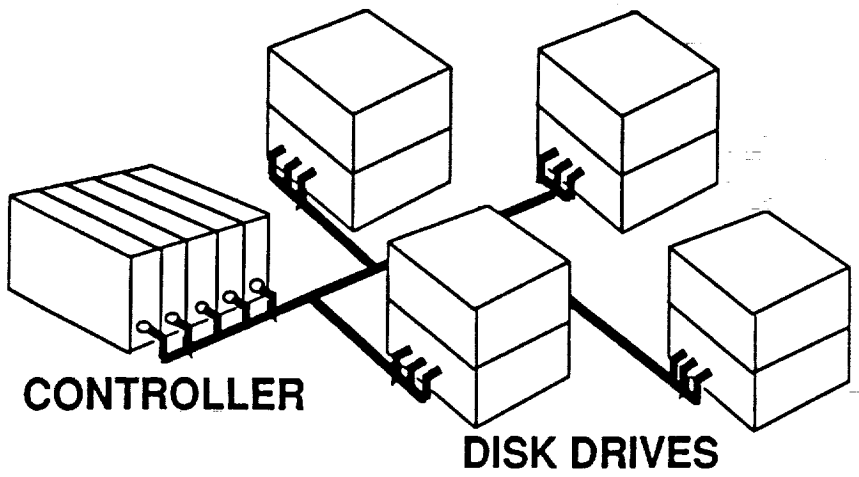
(facing page)



- **CAPABILITY**
  - -- HIGH DATA RATE
  - -- HIGH CAPACITY
  - -- LOW BIT ERROR RATE
  - -- RANDOM FILE ACCESS
- **RELIABILITY**
  - -- NO MEDIA OR HEAD WEAR
  - -- MECHANICAL SIMPLICITY
  - -- GRACEFUL DEGRADATION
- **VERSATILITY**
  - -- FIFO PLAYBACK
  - -- RATE CONVERSION
  - -- SIMULTANEOUS READ & WRITE
  - -- SELECTIVE DOWNLINK
  - -- INSTRUMENT INTERACTION

SODR SYSTEM CONCEPT

- CONFIGURABLE, EXPANDABLE ARCHITECTURE
- I / O RATE UP TO 2.4 GIGABIT / SECOND
- CAPACITY TO 1.28 TERABIT (160 GIGABYTE)
- SIMULTANEOUS INPUT AND OUTPUT
- RANDOM FILE ACCESS (250 MSEC)



PROGRAM DESCRIPTION

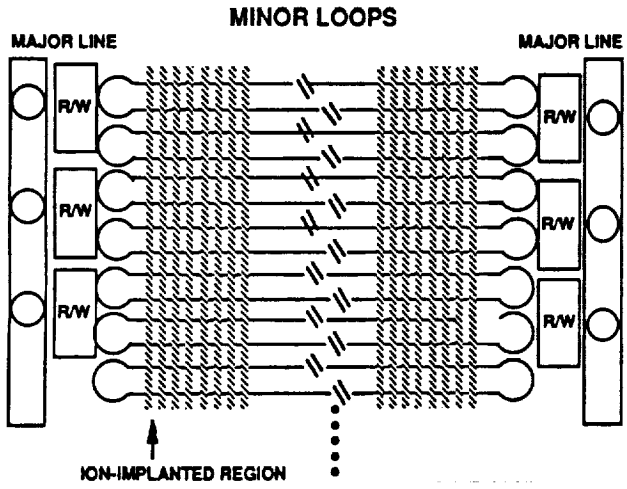
VBL-SSR

- Demonstrate solid-state recorder based on vertical Bloch line (VBL) storage technology
  - — High density, low power block access chips
  - — 1 Gigabit @ 1 Megabits / second recorder
  - — Scalable to 125 Gigabytes @ 1 Gigabits / second

NVRAM

- Demonstrate high density nonvolatile RAM chip based on magnetic effects
  - — 4 Megabits (>1 Mb/cm^2) @ <100 nanosec cycle time
  - — Inherently radiation hard and SEU immune

VBL DEVICE CONCEPT



- All solid-state, nonvolatile
- Serial read out by lines
- Parallel line read out
- Radiation & SEU hard
- Very high chip capacities
- 3D packaging compatible

APPROACH

SODR

- Develop single head Drive and perform Shuttle [Hitchiker] flight demonstration
  - — Validate fundamental storage & Drive mechanisms
  - — Develop prototype media and laser source
- Develop a full functioning engineering disk Drive for testbed demonstration
  - — 10 Gigabyte @ 300 megabits / second
  - — Two independent heads with complete data electronics
- Develop engineering Controller and perform testbed demonstration of dual port system with engineering Drive
  - — Simultaneous read and write @ 150 megabits / second
  - — Read or write @ 300 megabits / second (buffered)

APPROACH

(CONTINUED)

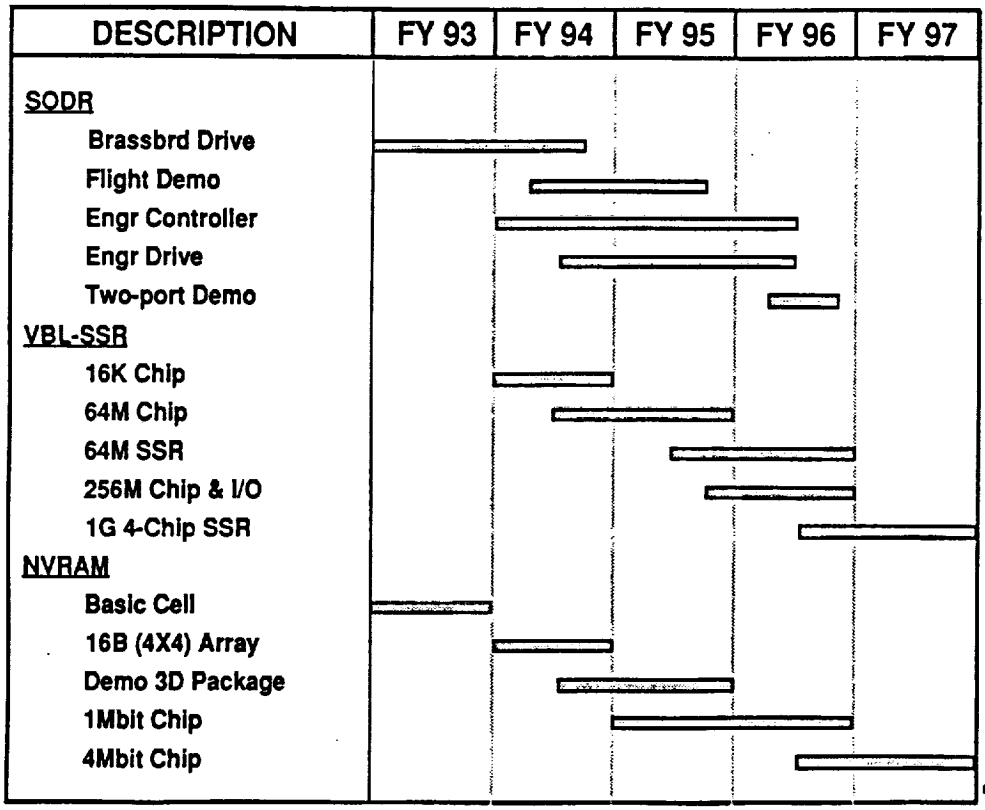
VBL-SSR

- Develop and perform laboratory demonstration of VBL chips and recorder
  - — Prove technology in manageable steps
  - — Design for scalability, chip and recorder

NVRAM

- Develop NVRAM chips and demonstrate as SRAM replacements
  - — Select basic cell structure / technology
  - — Demonstrate array of memory cells
  - — Demonstrate prototype memory chips

SCHEDULE



MEMORY & STORAGE
DSCS SPACE DATA SYSTEMS

RELATIONSHIP TO EXTERNAL PROGRAMS

SODR

- SODR Drive development receives DoD funding
- 5.25-inch MO Drive commercially available
  - — Multi-Drive systems under development
- Modified AF 5.25-inch Drive flown on STS
  - — 0.3 Gbyte @ 5 Mbps with removable media
- AF 14-inch Drive under development for aircraft
  - — 6 Gbyte @ 50 Mbps with removable media
  - — Some data electronics commonality

RELATIONSHIP TO EXTERNAL PROGRAMS

(continued)

VBL-SSR

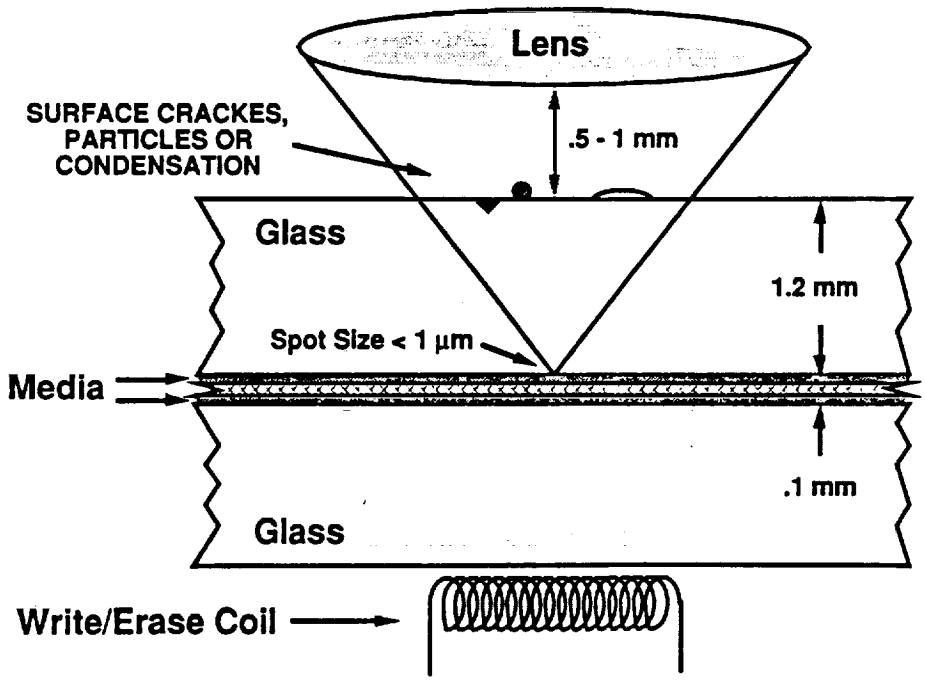
- VBL Device development receives DoD funding
- Commercial VBL-SSR under development in Japan
- Ruggidized VBL-SSR under development by French

NVRAM

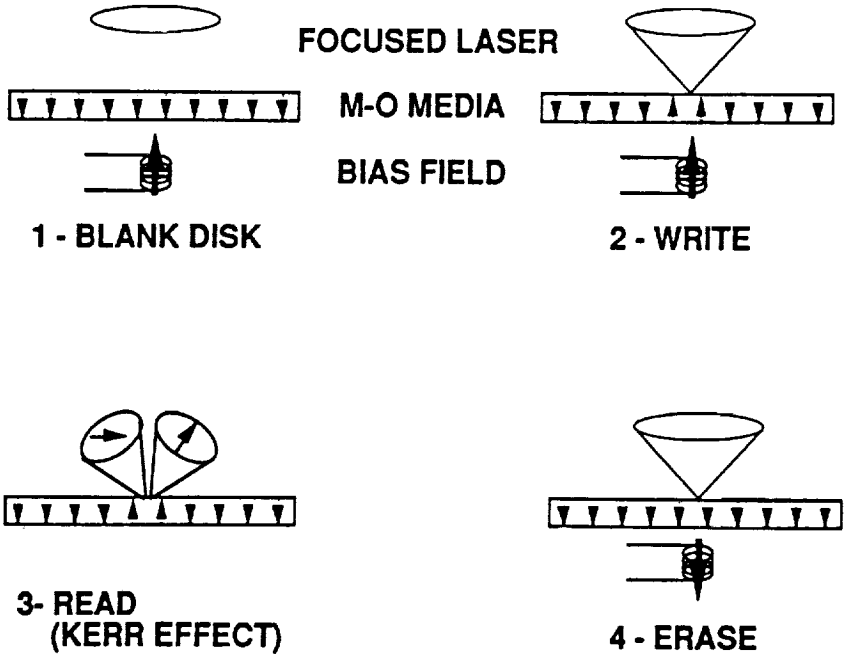
- Ongoing DoD NVRAM development programs
  - — MRAM (Honeywell), Ferroelectric RAM, Nitride EEPROM
  - — Operational and environmental performance concerns

---------- Backup Charts----------
for
Memory & Storage

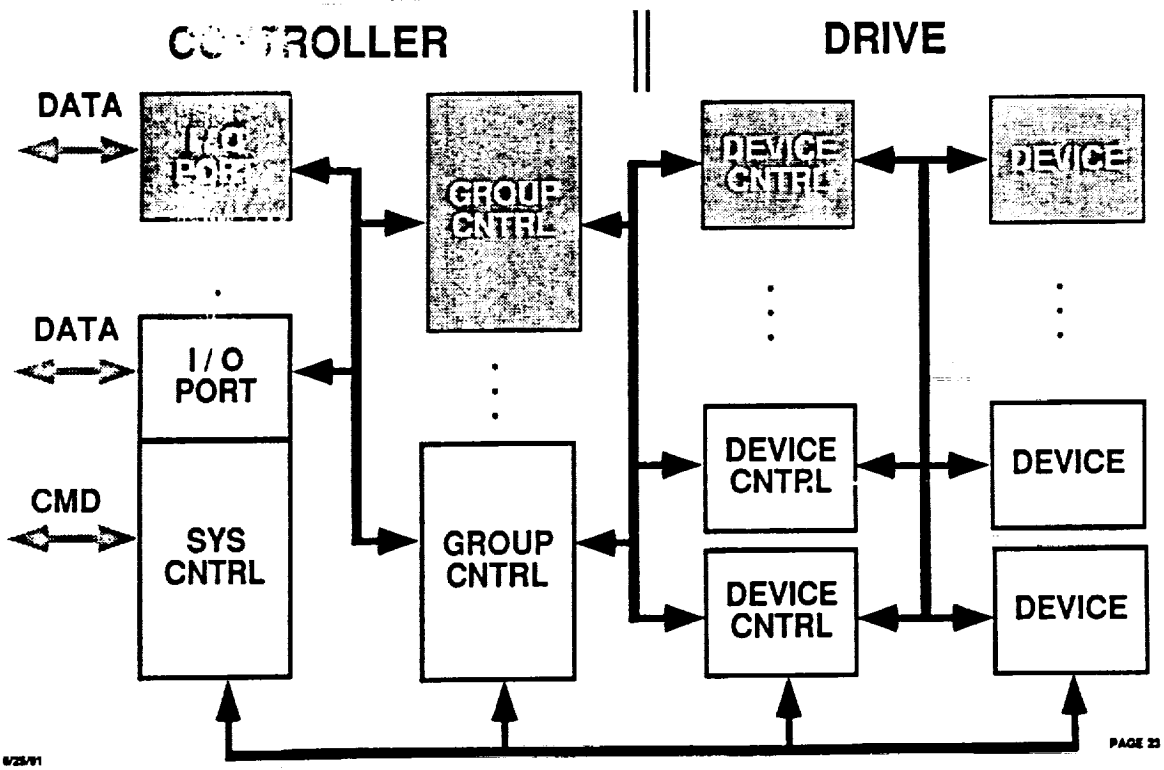
GLASS MO RECORDING



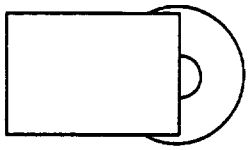
M-O PROCESS



EXPANDABLE ARCHITECTURE

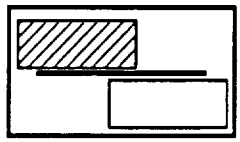


SODR PHASED PROGRAM



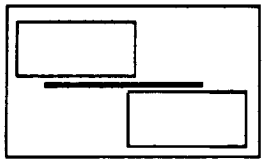
TECHNOLOGY DEMONSTRATION

MULTI-TRACK WRITE/READ/ERASE DEMO
14' MO MEDIA, DIODE LASER ARRAY



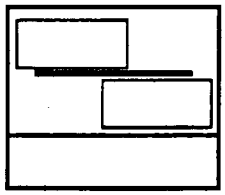
BRASSBOARD - DRIVE PACKAGING

FLIGHT DRIVE DESIGN - SINGLE HEAD DEMO
PROTOTYPE MEDIA & LASER DIODE
PRELIMINARY CONTROLLER DESIGN



ENGINEERING - FUNCTIONAL MODEL

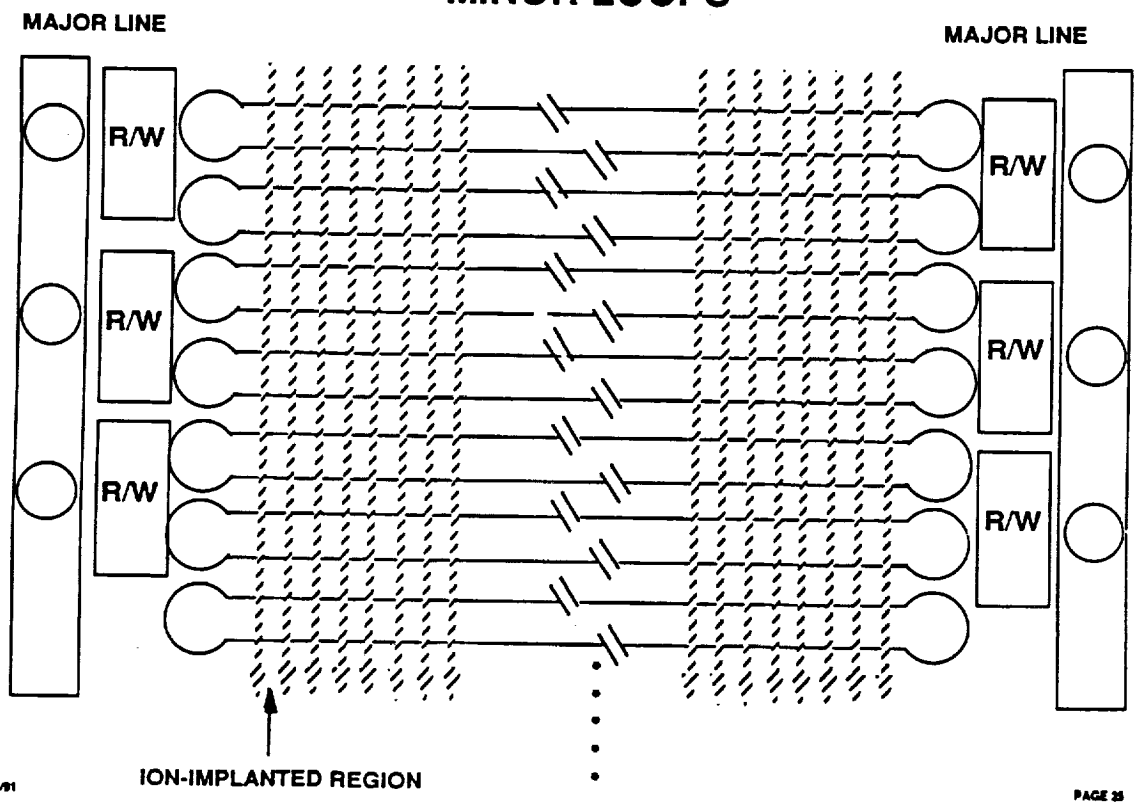
FULL FUNCTIONING DRIVE & CONTROLLER
PACKAGED FOR TEST-BED ENVIRONMENT
TWO PORT SIMULTANEOUS READ / WRITE



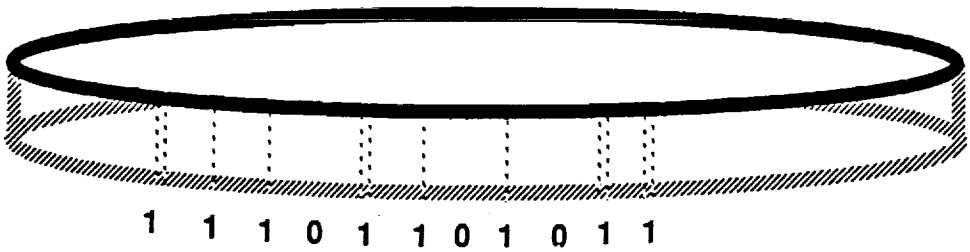
FLIGHT PROTOTYPE - QUALIFICATION

FLIGHT QUALIFIED DRIVE & CONTROLLER
COMPLETE PARTS (ASIC / VLSI) DEVELOPMENT
TWO DRIVE DEMO WITH ENGINEERING MODEL

MINOR LOOPS



VERTICAL BLOCH LINE MEMORY ADVANTAGES



- The wall of a single stripe domain can contain thousands of VBL's
- The VBL's can be circulated around the domain like a disk or recording tape, but magnetically, without any moving parts
- The presence or absence of VBL's representing "1's" and "0's" can be detected as they come by the end of the domain
- VBL's can be created or annihilated there, too, allowing us to read and write in the memory
- The in / out device can be made on part of the same material that holds the magnetic domains

SAMPLE DOD TECHNOLOGIES

- MRAM (Honeywell)
  - — Read times increase (1 to 10 μs) as chip density increases
  - — Leads to low data rates and long access times
  - — Really aimed at replacing core memory
- Ferroelectric RAM technology
  - — Material fatigue causes chip failure by 10^{11} cycles
  - — Interdiffusion between ferroelectric and metal contact materials degrades performance
  - — Leads to limited testability, low reliability, and limited utility
- Nitride EEPROM technology
  - — Material cyclability limited to around 10^{5} cycles
  - — Radiation soft, long write times, limited data retention times
  - — Leads to limited testability, low reliability, and limited utility

External Review of the
Integrated Technology Plan for the Civil Space Program

SPACE DATA SYSTEMS

ADVANCED FLIGHT COMPUTERS

Harry F. Benz

Langley Research Center

June 26, 1991

Office of Aeronautics, Exploration and Technology
National Aeronautics and Space Administration

TECHNICAL OBJECTIVES

Develop high-performance, space-qualifiable, onboard computing, storage, and networking technologies

- **Space qualifiable, RAD-hard, SEU-immune 32-bit computer system**
  - **1-2 Mips / Watt**
  - **Scalable (3-20 Mips)**
- **Evolutionary development path for hardware, software, and systems**
- **Full development environment**

FLIGHT COMPUTERS

JUSTIFICATION

NASA has unique computer system requirements

- 30 Year life with no interruptions, self validating
- Low power, SEU-immune, total dose radiation hard, mass constrained
- One-of-a-kind mission critical applications (requires in-house infrastructure)

Reduce technology gap

GAO noted 8-20 year lag from commercial introduction to space mission use and asserted:

"Nation's leadership in space depends upon....incorporating more up-to-date computer systems in its programs."

SSTAC Ad Hoc Subcommittee on Onboard Processing and Data Management Technology (1987) concluded:

"...highest priority recommendation is for the accelerated development of...fault-tolerant onboard information management systems...nation's most challenging reliability requirement...at regular intervals for transition into NASA missions."

"Blue Ribbon" Panel validated GAO recommendation and recommended:

"...aggressive program for NASA to meet its needs."

DoD controls export of these technologies under MCTL 2.0, 7.1 and ECCN 1564A, 1565A, and 1574A

6/28/91 8:17 PM

FLIGHT COMPUTERS

DSCS — SPACE DATA SYSTEMS

TECHNOLOGY CHALLENGES

- Completeness of system and software tools to reduce life-cycle costs
- SEU-immunity, flight qualifiability (QML)
- Performance
  - Relevance: Include I/O and context switches, benchmarks of characteristic applications
  - Realism: Use realistic timings based on space parts
  - Efficiency: Performance / Watt
- Architectural support for fault-tolerance and multicomputers
- Evolvability with improved technology
  - From program to program (heritage)
  - Within a program (Space Station, Lunar Base)

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STATE-OF-THE-ART-ASSESSMENT

(facing page)

MISSION EPOCH	PROC TYPE	MISSION	READINESS AS OF 4/91	PERFORMANCE	CPU CHIP SET PWR	RAD HARD CHARACTERISTICS
70'S	1802	GALILEO	FLOWN	100 KIPS 1802	0.5W	TOTAL DOSE—YES SEU—YES OLD 4 MICRON TECH NO LONGER AVAILABLE
80'S	80C86	MAGELLAN	FLOWN	250 KIPS 8086	0.5W	TOTAL DOSE—YES SEU LATCH UP—YES UPSET—LIMITED
90'S	80386	SSF/	LEVEL 6	3 MIPS VAX	2.5W	NOT RAD HARD UNKNOWN LATCHUP WILL UPSET WITH SEU
	80486	SSF	LEVEL 5	10-12 MIPS VAX	3.5W	NOT RAD HARD UNKNOWN LATCHUP WILL UPSET WITH SEU
	GVSC 1750	CRAF / CASSINI, EOS	LEVEL 5	2-4 MIPS DAIS	5W	ALL—YES
	SA 3300	MM2	LEVEL 5	750 KIPS VAX 32000	1.5W	ALL—YES
	80586	SSF	LEVEL 2	20-25 MIPS VAX	4.5W	NOT RAD HARD UNKNOWN LATCHUP WILL UPSET WITH SEU
2000'S	RH-32	SDIO-BSTS / AWS	LEVEL 2	20 MIPS RISC	3W	ALL—BY CURRENT DESIGN

NOTE: RH-32 is currently underfunded to meet its objectives

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DSCS — FLIGHT COMPUTERS — SPACE DATA SYSTEMS

STATE-OF-THE-ART ASSESSMENT

- **Current state-of-the-art for spaceborne computational systems is 12 years behind ground based embedded computers**
- **80C86 is most recently flown technology which meets SEU, power, and performance goals**
- **CRAF / CASSINI-EOS are GVSC-1750A, 16 bits, 3MIP DAIS, 5W**
- **SSF 80386 is not SEU-hard, probably will not latch-up, 16 / 32 bits, 3 MIP VAX, 2.5W**
- **RH32, RH3000, and ATIM-R6000 are seriously underfunded by SDIO / AF to meet their objectives, and are slipping faster than the calendar**

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FLIGHT COMPUTERS

PROGRAM DESCRIPTION

PRODUCTS/PAYOFF/DELIVERABLES

- GVSC, SA3300, and RH-32
  - — Processor evaluation
  - — Multiprocessor architecture development
  - — Performance and functional models
- Common spacecraft multiprocessor operating system coarse grained data flow operating system for embedded applications development tools brassboard application demonstrations
- Complete qualifiable chip set for advanced flight computer
- Qualifiable single board 3-15 Mips, 32-bit 1-2 Mips / Watt computer
- Complete software set
  - — Operating system
  - — Compiler(s) (including Ada) and runtime library
  - — Debugger(s)
  - — Models
- Technology transfer to flight projects through active multicenter participation, review, and testbed activities and project specific hardware configuration modeling
- Preparation for follow-on generation

NOTE: All deliverables to level 5 technology readiness

6/28/91 8:17 PM

DSCS — SPACE DATA SYSTEMS

FLIGHT COMPUTERS

APPROACH

Build on DoD, commercial, and academic developments

- Use models, benchmarks, in-house evaluations, and reviews to select specific approach based on NASA criteria

Demonstrate and develop sources for the full line of computer systems products

- Include hardware, software, and system tools
- Support all needed architectural configurations (single board / multiprocessor / multicomputer / parallel / fault-tolerant)
- Full chip set for computer (including I/O) not just processor
- Assure future support, availability for use by commercial space companies
- Teams approach: In-house, QML semiconductor manufacturer, computer system house, academic, other government partners

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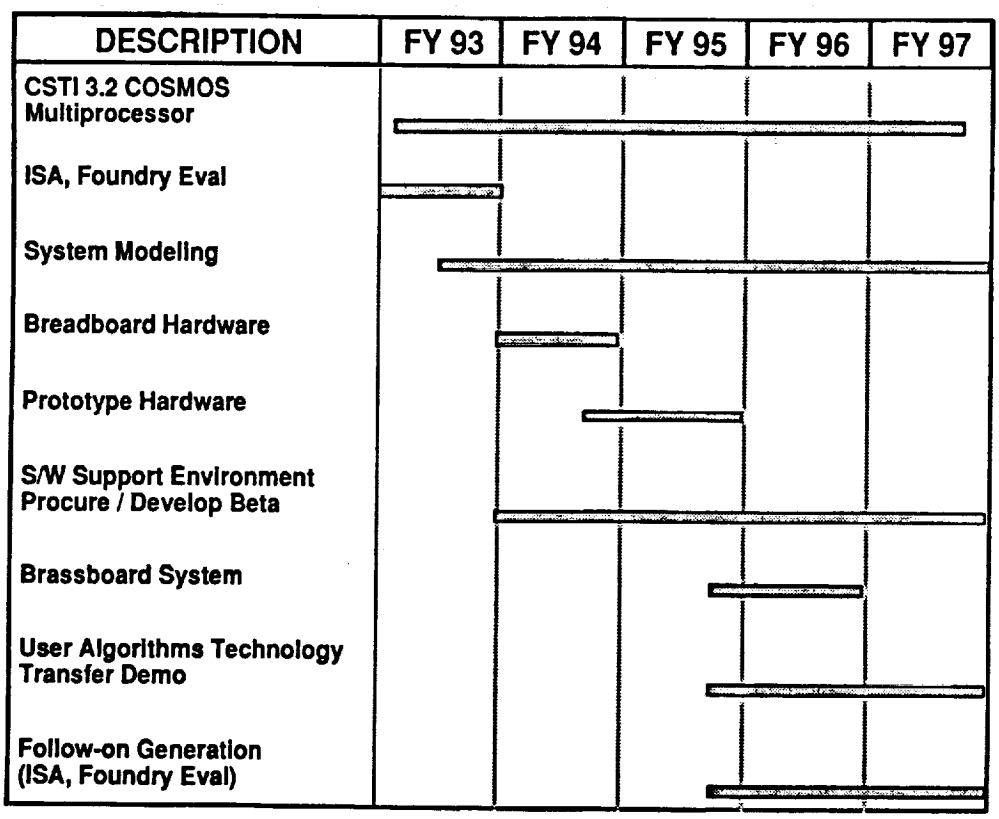
FLIGHT COMPUTERS

SCHEDULE



DSCS SPACE DATA SYSTEMS

FLIGHT COMPUTERS

RELATIONSHIP TO EXTERNAL PROGRAMS

- Cofunded multiprocessor application with SDIO
- Participate in CAP-16, GVSC/ASCM, RH-32 / ATIM programs and reviews
- Related to HPCC-REE elements in Advanced Multicomputer Architectures for Spacecraft Applications which depends on this augmentation for flight qualifiable singe board computer components
- EOS-A and Craf / Cassini early interest in GVSC for use as Engineering Flight Computer

COOPERATION & COORDINATION EFFORT

- Coordinated with AF through STIG sub-panel with opportunity for co-development (Air Force initiative to replace loss from SDIO)
- Coordinated with SDIO through PMA-TIM's; AF-Phillips Lab; AF-Rome Lab; USA-SDC, Huntsville; USN-NRL
- Coordinated with DARPA / ISTO in evaluation of parallel and distributed processors (iWARP, Multimax, Gigamax)
- Cooperative effort with Software Engineering Institute (SEI) for software development and verification tools for ADA language
- Cooperative effort with Institute for Defense Analysis (IDA) on real-time scheduling algorithms for uni- and multiprocessor systems
- Coordinated with NASA Space Engineering Research Center for VLSI Systems Design (Idaho) and Illinois Computer Laboratory for Aerospace Systems and Software (Illinois)

6/25/91 8:17 PM

External Review of the
Integrated Technology Plan for the Civil Space Program

SPACE DATA SYSTEMS

SPECIAL PURPOSE FLIGHT PROCESSORS

Mike Henry

Jet Propulsion Laboratory

June 26, 1991

Office of Aeronautics, Exploration and Technology
National Aeronautics and Space Administration

CS

SPECIAL PURPOSE PROCESSORS

TECHNICAL OBJECTIVES

Develop high-performance, space-qualifiable, onboard computing, storage, and networking technologies

- Demonstrate space qualifiable science and automation processors
  - — Geophysical / biophysical parameter extraction
  - — Low distortion, high ratio (> 50:1) lossy data compression
  - — Panchromatic scene analysis
  - — Multi-sensor coordination and data fusion operations
  - — Synthetic Aperture Radar processing
- Demonstrate space qualifiable supporting components
  - — Correlators
  - — Data compressors
- Utilize state-of-the-art Application Specific Integrated Circuits
  - — VLSI custom and semicustom
  - — Design synthesis
  - — System / component behavioral modeling
  - — Advanced packaging

SPECIAL PURPOSE PROCESSORS

JUSTIFICATION

- Planned imaging systems will saturate storage and communications systems (e.g. SAR 300Mbs, HIRIS >400Mbps)
- Without new on-board processing technology, we must back off science capabilities
- Enable target-of-opportunity detection and location
- Special purpose processors achieve 5 to 50 time the operations per Watt efficiency for specific tasks
- Advanced microelectronics technology required to develop and field special purpose processors

SPECIAL PURPOSE PROCESSORS

DSCS — Space Data Systems

JUSTIFICATION

(facing page)

Target applications

- SAR image generation / data compression
  - — EOS SAR
- Information Extraction
  - — HIRIS; image spectrometry
- Autocorrelator
  - — Balloon MLS
  - — EOS MLS
- Cross Correlator
  - — Submillimeter Interferometer

SPECIAL PURPOSE PROCESSORS

APPROACH

- Advanced Image Processor
  - Involve science community: requirements and evaluation
  - Map a representative set of algorithms into an adaptable architecture
  - Level 5 demonstration: fault tolerant, flight qualifiable technologies
- Digital Autocorrelator Spectrometer
  - Prove technology in manageable steps (generations)
  - Build on microelectronics technology improvements
  - Demonstrate spectrometer level breadboards
- High Speed Cross Correlator
  - Develop high speed, > 1 GHz sample rate, low power circuit elements leveraging off of NASA and DoD ongoing programs
  - Develop chip design in full custom VLSI using developed elements
  - Fabricate chip and demonstration hardware

SPECIAL PURPOSE PROCESSORS

DSCS — Space Data Systems

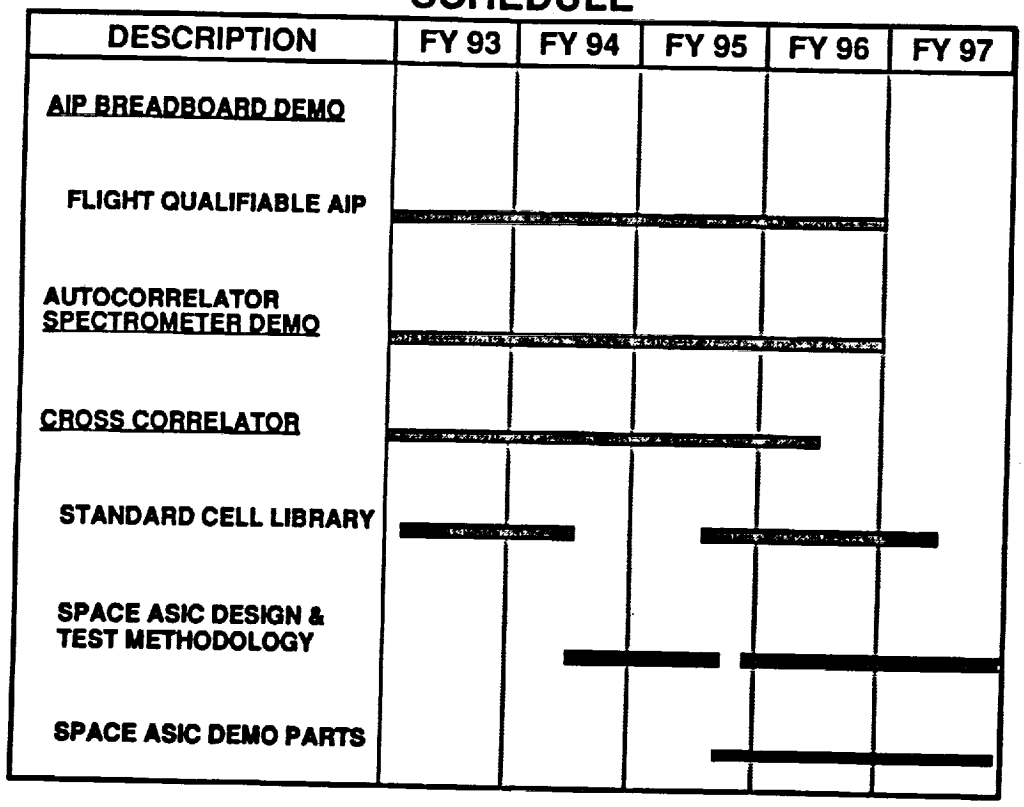
APPROACH
(CONTINUED)

- Microelectronics
  - Work with other NASA offices to demonstrate and qualify ASIC development capabilities
  - Work with other NASA offices to demonstrate and qualify high density packaging technologies
  - Work with the ASIC industry to enhance semicustom and custom ASIC design tools, libraries and methods to incorporate space qualified issues
  - Demonstrate the feasibility of ASIC designs by prototyping example components

SPECIAL PURPOSE PROCESSORS

DSCS — DATA SYSTEMS & COMPUTER SCIENCE

SCHEDULE



DEE/MDH 1

SPECIAL PURPOSE PROCESSORS

DSCS — Space Data Systems

PROGRAM DESCRIPTION

PRODUCTS/PAYOFF/DELIVERABLES

- Breadboard Advanced Image Processor: multispectral analysis applications
- Qualifiable brassboard AIP: multispectral, panchromatic, SAR, compression
- 30 mW/channel, 5 MHz digital autocorrelator (DAC) spectrometer breadboard demonstrated for EOS Microwave Limb Sounder (400 pJ / sample / channel at the chip level)
- Engineering versions of 1000 MHz autocorrelator and cross correlator chips (80 pJ / sample / channel at the chip level)
- Digital cross correlator chip to enable space based submillimeter interferometer correlation to provide high ratio data compression
- (With code Q) Identification of flight qualified foundries, design procedures, and validation procedures for application specific integrated circuits (ASIC)
- Standard libraries and synthesis tools for flight qualified ASIC
- Prototype ASIC parts to validate and demonstrate the approach

DEE/MDH 7

SPECIAL PURPOSE PROCESSORS

DSCS — Space Data Systems

STATE-OF-THE-ART ASSESSMENT

- Image processors
  - — Bulky & power hungry (1 m^3, 2.7 Mops / Watt : SAR)
  - — DoD developed processors will have good efficiency, but don't address all the computing needs for our target algorithms
- Components
  - — Correlators

    Narrow bandwidth: 100-200 MHz Bandwidth

    High power: 250 mW / channel

    (750 pJ / channel / sample at the chip level)
  - — Microelectronics

    Class S ASIC foundries under DoD development

    No qualified design methodology

6/21/91 DEE/MDH 6

SPECIAL PURPOSE PROCESSORS

DSCS — Space Data Systems

TECHNOLOGY CHALLENGES

- Low power/mass/volume, high performance digital signal processors: at least 20 MFLOPS per Watt
- Long Mission Duration (15+ years) Reliability / fault tolerance
- Environment—RAD-hard to 100 krad Si, SEU immunity to 40 LET
- Design and operations adaptability
- 1-10 GHz sampling rate correlators
- High rate intraprocessor communication (up to gigabits per second)
- Low cost ASIC Design, Develop, Test, and Qual
- Second source ASIC capability
- Wafer Scale Integration

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RELATIONSHIP TO EXTERNAL PROGRAMS

- DoD has ongoing signal processor and packaging development programs (*e.g.* PMA F1104: ASSP, 3D Computer, Wafer Scale Processors, *etc.*)
  - — Augment with NASA funding to achieve critical mass if necessary
  - — Demonstrate applications/algorithms separately
- DoD signal processors are being fielded on aircraft
  - — Early AIP work is based on such a DoD architecture
- DoD developing Qualified Manufacturing Lines (QML)
  - — Utilize, where possible for NASA space parts
  - — Demonstrate applicability to NASA users
- VHSIC Hardware Design Language (VHDL)
  - — Leading candidate tool for NASA design methodology

SSTAC Review of the
Integrated Technology Plan for the Civil Space Program

DATA SYSTEMS & COMPUTER SCIENCE
SPACE DATA SYSTEMS

ONBOARD NETWORKING & TESTBEDS

DAN DALTON

June 26, 1991

Goddard Spaceflight Center

NETWORKING & TESTBEDS

TECHNICAL OBJECTIVES

Develop high-performance, space-qualifiable, onboard computing, storage, and networking technologies

Objectives for Onboard Networking & Testbeds

- Develop a low-power, multi-gigabit space-qualifiable Data Network
- Pursue / Select Industry Standards for onboard systems
- Develop and demonstrate Network ComponentTechnology
  - Multi-purpose fiber optic transceiver (MFOX) technology
- Develop a Flight Systems Validation Laboratory

JUSTIFICATION

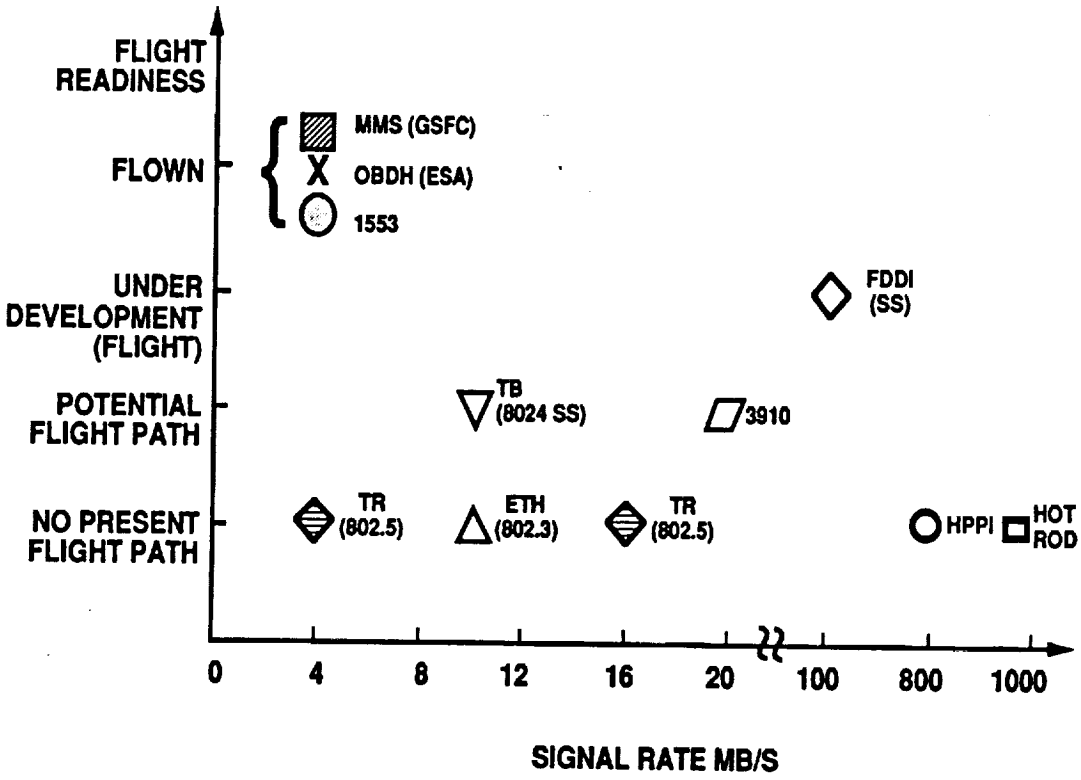
- Technology readiness
  - — Limits technology path to flight
- Mitigate technology risk for flight projects
  - — Demonstrate technology benefits without baseline
- Technology leveraging from emerging technologies
  - — Testbed for demonstrating
- Testbed Benefits / Existing

NETWORKING & TESTBEDS
DSCS SPACE DATA SYSTEMS

TECHNOLOGY CHALLENGES

- Size(1 in^3 per node), Weigh (<.25 lb.per node), and Power (<100 mW per node)
- High Data Rate Components (10 Giga bit/S)
- High Density Packaging Qualification
- Maturing of Data System Standards

STATE-OF-THE-ART ASSESSMENT



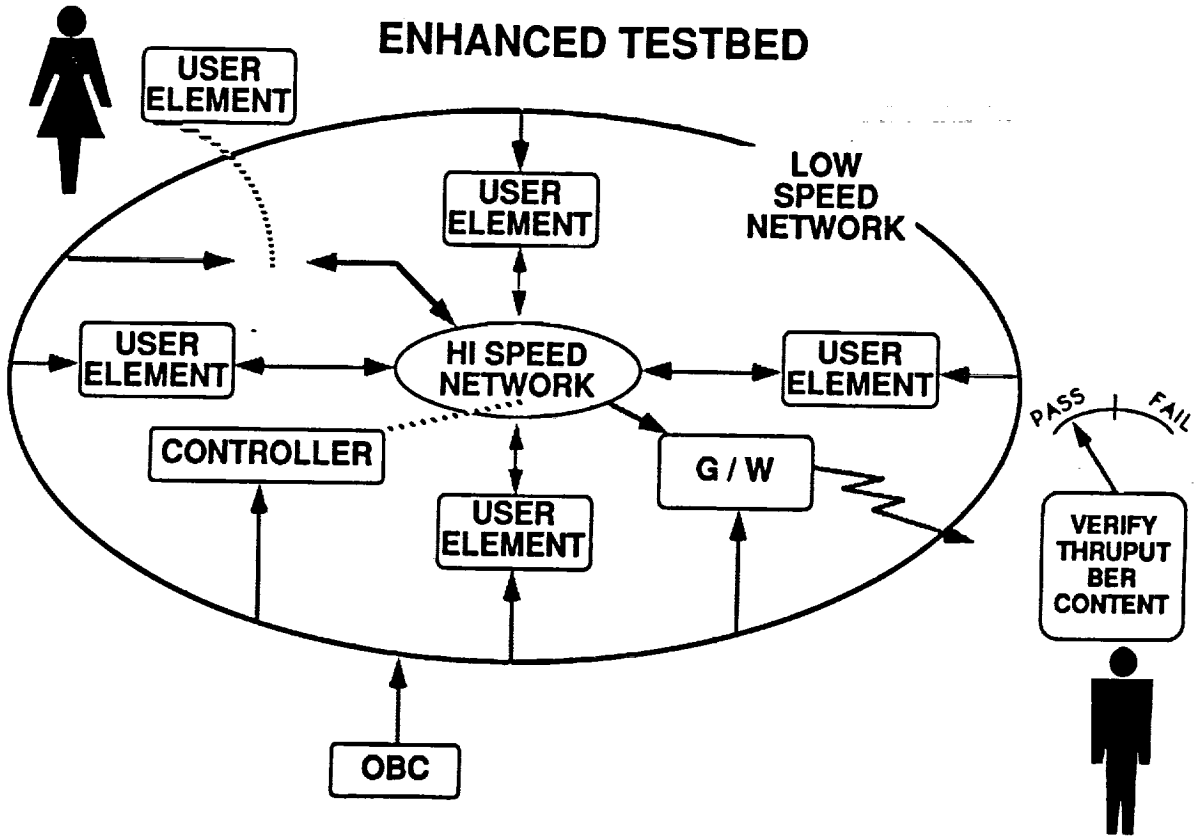
NETWORKING & TESTBEDS
DSCS — SPACE DATA SYSTEMS

PROGRAM DESCRIPTION

PRODUCTS/PAYOFF/DELIVERABLES

- Definition of Network requirements
  - — Future Project requirements
- Modular building blocks defined and developed
  - — Reconfigurable testbed
- Development of an Advanced Orbiting Platform network
  - — Prototype data system
- Development of a Lunar base network
  - — Prototype data system
- Technology insertion assessment for next network development
  - — Accommodate emerging technology
- Tools / simulators / models for flight system intergration and development
  - — Analysis and evaluation
- Performance evaluations with flight elements
  - — Processor development
  - — Storage development
  - — Industry IR&D

ENHANCED TESTBED



NETWORKING & TESTBEDS
DSCS SPACE DATA SYSTEMS

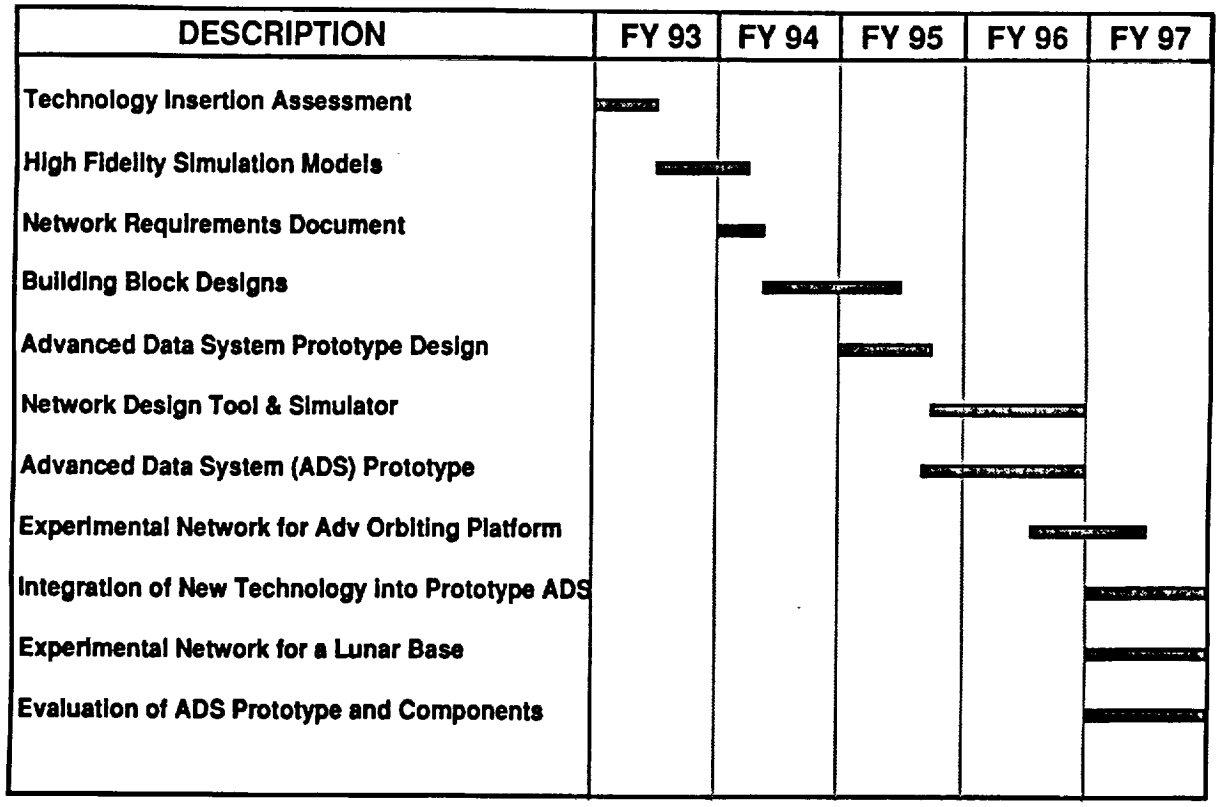
APPROACH

- Project requirements for future data systems
- Perform trades of existing technology
- Evaluate existing / emerging standards
- Design system to meet future requirements
- Develop environment / tools as required
- Integrate testbed
- Integrate and test storage and processor developments

NETWORKING & TESTBEDS

DSCS — SPACE DATA SYSTEMS

SCHEDULE



External Review of the
Integrated Technology Plan for the Civil Space Program

SCIENCE INFORMATION SYSTEMS

ARCHIVE, ACCESS & RETRIEVAL

William J. Campbell
Data Management Systems Facility
Goddard Space Flight Center

June 26, 1991

Office of Aeronautics, Exploration and Technology
National Aeronautics and Space Administration

OBJECTIVES

Develop technology for automated characterization, and interactive retrieval and visualization of very large, complex scientific data sets

- **Specifically, Develop Technologies for**
  - **Rapidly Archiving Data Sets**
  - **Automatically Characterizing & Labeling Data in Near-Real Time**
  - **Providing Users Ability to Browse Contents of Databases Efficiently and Effectively**
  - **Providing Users Ability to Access and Retrieve System Independent Data Sets Electronically**
  - **Automatically Alerting Scientists to Anomalies Detected in Data**

JUSTIFICATION

- Scientists Increasingly Spend More Time on Accessing & Retrieving Data, Lessening Time for doing Science
- Scientists Need to Become Proficient Data Technicians to Convert Acquired Data Into Appropriate Form
- There are no Available (Commercial or Non-DOD) Data Management Systems that can handle the Projected Data Rates and Volumes
- It is Humanly Impossible to Manually Inspect The Projected Data Volumes
- Massive Amounts of "RAW" Uncharacterized Data Sets Produce Much Duplication of Effort by Scientists

ARCHIVE, ACCESS & RETRIEVAL
DSCS SCIENCE INFORMATION SYSTEMS

TECHNOLOGY CHALLENGES

- Mass Storage Organization
  - Layout of contents on mass storage
  - How the mass storage system interacts with the rest of the system
- Automatic Data Characterization & Labeling
  - Develop algorithms for metadata extraction based on needs of scientific community
  - Real-time performance
  - Quality and robustness of system
- Browsing Mechanism
  - Query Expressibility
  - Spatial, Temporal, Spectral, Data Content, Sensor, Discipline, Project

TECHNOLOGY CHALLENGES (Continued)

- Data Organization
  - Object-Oriented Technologies
  - Relational Databases
  - Search Indices (Spatial, Spectral, Data Content, Discipline, Sensor, Temporal, Project)
- Multidisciplinary Research Tools
  - Data Fusion, Georegistration
  - Different Vocabulary Across Domains

ARCHIVE, ACCESS & RETRIEVAL
DSCS SCIENCE INFORMATION SYSTEMS

STATE OF THE ART:	Today	Target
Mass Storage Organization	• Commercially Available • No Functional Layout Optimizations	• Data Organized Based on Semantic Groupings • Simulation Models for Data Flow, Interactions with Rest of System
Automatic Data Characterization & Labeling	• Statistical Image Segmentation - Time Consuming - CPU Intensive - No Labeling of Segments	Technologies & Techniques • Knowledge Bases • Expert Systems • Neural Networks • Statistical Methods
Browsing Mechanism	• Slow • Off-Line • Multiple Models • Limited Query Expressibility	• Fast Display Algorithms • On-Line • Lossless Data Compression • Non-Visual Aids • Personalized Tool Kits
Data Organization	Most Data Off-Line Relational DBMS • Slow • Limited Expressiveness • Redundant	On-Line – Object-Oriented DBMS • Fast • Multidisciplinary Queries • Extended Search Methods, Data Types
Multidisciplinary Research Tools	• Manual Georegistration • Manual Analysis • Labor Intensive	• Automatic Georegistration • Automatic Methods for Data Fusion • Hyper Media to Locate/Identify Data Bases/Sets • Multiple Database Access

PROGRAM DESCRIPTION
Payoff

- Opportunity for New Scientific Discoveries
- Enhance Capability for Multidisciplinary Research
- Provide Faster Scientific Turn-Around
- Supports Large User Community - Increased Efficiency
- Improved Understanding of Scientific Data Holdings

ARCHIVE, ACCESS & RETRIEVAL
DSCS SCIENCE INFORMATION SYSTEMS

PROGRAM DESCRIPTION
Deliverables

- MASS STORAGE TESTBED SCALABLE TO REAL SYSTEM NEEDS

  Data organized on physical storage based on semantic groupings.

  Minimizes overall access time, reduces stress on robotic machinery, faster user-response times.

- AUTOMATED DATA ARCHIVE

  Automatic populating of distributed databases at data rates comparable to average rates of EOS instruments.

  Automatic extraction of metadata including some description of image content; organization of fast search indices.

  Permits scientists to request data by a variety of attributes, including image content.

- ADVANCED BROWSE

  Tools for viewing transmitted images, including fast image reconstruction algorithms and methods for directly analyzing compressed data.

  Methods for focusing user interactions with underlying databases.

PROGRAM DESCRIPTION
Deliverables (Continued)

- **ADVANCED DBMS**

  Development of rapid access data structures, methods for interacting with relational and object-oriented databases, and natural language interfaces to underlying databases.

  Transparent access to data sets, use of specialized data structures to handle storage and access to high volumes of scientific data.

- **SUITE OF MULTIDISCIPLINARY RESEARCH TOOLS**

  Steps toward the automatic georegistering of images and the fusing of data sets. Approaches to handling queries whose solutions require accessing multiple databases.

  Ability for scientists to use a single system to browse and access multiple databases and fuse the results.

ARCHIVE, ACCESS & RETRIEVAL
DSCS SCIENCE INFORMATION SYSTEMS

SCIENCE INFORMATION SYSTEM ARCHIVE, ACCESS, & RETRIEVAL	APPROACH Mass Storage Organization				
	FY93	FY94	FY95	FY96	FY97
Acquisition of Data for Testing					
Logical Organization					
Simulations					
Interfacing with Rest of System					
Issues Related to System Evolution					
Use of Redundancy					
Dynamic Reorganization Methods					

ARCHIVE, ACCESS & RETRIEVAL

DSCS — SCIENCE INFORMATION SYSTEMS

SCIENCE INFORMATION SYSTEM ARCHIVE, ACCESS, & RETRIEVAL	APPROACH Automatic Data Characterization and Labeling				
	FY93	FY94	FY95	FY96	FY97
Acquisition of Ground Truth, Satellite Imagery, & Georegistration					
Exploration of Methods for Extracting Metadata					
Comparison with Conventional Methods					
Sampling Theory, Data Distributions					
Methods for Analyzing Robustness & Performance of Metadata Extraction Algorithms					
Planning & Scheduling For Metadata Extraction					
Methods for Signature Extension					
Construction of Domain-Specific Knowledge Bases					
Real-Time Expert Systems					
Reasoning with Uncertainty					
Interactions with Rest of System					

ARCHIVE, ACCESS & RETRIEVAL

DSCS — SCIENCE INFORMATION SYSTEMS

SCIENCE INFORMATION SYSTEM ARCHIVE, ACCESS, & RETRIEVAL	APPROACH Browsing				
	FY93	FY94	FY95	FY96	FY97
Development of Fast Image Reconstruction Algorithms					
Progressive Layering for Browsing at a Distance					
Toolkits for Building Personalized User Interfaces					
Methods for Handling Temporal Queries					
Methods for Focusing User Interactions with the Underlying System					
Methods for Passive Querying					
Methods for Directly Analyzing Compressed Data					
Methods for Interfacing with User Developed Display Algorithms					
Explore Additional Methods to Aid in Browsing					

ARCHIVE, ACCESS & RETRIEVAL

SCIENCE INFORMATION SYSTEM ARCHIVE, ACCESS, & RETRIEVAL	APPROACH Data Organization				
	FY93	FY94	FY95	FY96	FY97
Modeling of Domains					
Tools for Populating, Querying					
Rapid Access Data Structures					
Methods for Interacting with Relational Databases					
Improvements in Lossless Compression					
Distributed Object-Oriented Databases					
Natural Language Interfaces					
Efficient Mapping of Query Components to Object-Oriented Databases					
Implementation of a Query Optimizer for Object-Oriented Databases					

ARCHIVE, ACCESS & RETRIEVAL

SCIENCE INFORMATION SYSTEM ARCHIVE, ACCESS, & RETRIEVAL	APPROACH Multidisciplinary Research Tools				
	FY93	FY94	FY95	FY96	FY97
Methods for Automatic Georegistering of Images					
Use of Hypermedia to Aid Users in Identifying and Accessing Pertinent Databases					
Use of Neural Networks and Expert Systems for Fusing Data Sets					
Methods for Deriving Results that Require Accessing Multiple Databases					
Detection of Inconsistencies among Multiple Databases					

RELATIONSHIP TO EXTERNAL PROGRAMS

	US GOVERNMENT								Commercial	
	NASA				NCAR	DoD	DOE	Intelligence Community	Oil Companies	Aerospace Companies
	EOSDIS	GSFC	JPL	ARC						
Large Mass Storage	Very large [1][2]	Very Large [1]	No known activity	Large [1]	Large [1][2]	Moderate [1][2][4]	Large [1][2]	Very large [1][2]	Large [1][2]	Very Large [1][2]
Volume (bytes)	20.00E+15	300.00E+12	n/a	20.00E+12	100.00E+12	1.00E+12	100.00E+12	10.00E+15	10.00E+12	10.00E+12
Application	Test, model, images, pictures analysis data	Earth & Space related Computer modeling, analysis, Sensor data	n/a	Fluid, aerospace modeling, analysis, data visualization	Models, images, data, analysis	Test, model, images, pictures, analysis data	Models, images, analysis, sensor data	Test, model, images, pictures analysis data	Models, images, analysis, sensor data	Models, images, analysis, sensor data
Automated Storage Optimization	none	none	n/a	none	none	none	none	none	none	none
Integrated DASD	Large	Small [3]	No known activity	Moderate	Moderate-Large [3]	Small-Moderate [3]	Moderate [3]	Large	Moderate	Moderate
Volume (bytes)	500.00E+09	20.00E+09	n/a	30.00E+09	100.00E+09	10.00E+09	60.00E+09	300.00E+09	60.00E+09	60.00E+09
Integrated Metadata Management	Large application Data systems [3]	Large application metadata systems	Large application metadata systems	File management Systems	File management Systems	Large application metadata systems [3]	File management Systems	Large application Data systems	File & data mgmt systems	File & data mgmt systems
Integrated Product Browse	Limited image, model, sensor data, not very fancy	Limited image, model, sensor data	Meta data	Limited image, model, sensor data, not very fancy	Limited image, model, sensor data, not very fancy	Application unique, images & data (Classified) also file data [3]	Application unique, limited (Classified) also file data	Application unique, images & text (Classified) also file data	Application unique, limited (proprietary) also file data	Application unique, limited (proprietary) also file data
Automated Data Labeling & Characterization	Simple PLDS based ingest processing	Code R funded research project	n/a	none	not known	not known	none	Powerful image, textual software	none	none
Multidisciplinary Research Tools	One of the primary focuses of the Project. Expected to be large nos. of tools developed	Limited software in NCDS, visualization tools under development	n/a	Yes, not applicable to Earth/Space research	yes, might be applicable to NASA missions	yes, not applicable to NASA missions	yes, not applicable to NASA missions	yes, might be applicable to NASA missions however very classified	Application unique, limited (proprietary)	Application unique, limited (proprietary)

[1] Mass store driven by super computing applications
[2] Mass storage driven by data collection applications
[3] Not integrated
[4] No on-line data presently, most off-line

External Review of the
Integrated Technology Plan for the Civil Space Program

SCIENCE INFORMATION SYSTEMS

VISUALIZATION

Ray J. Wall

Jet Propulsion Laboratory

June 26, 1991

Office of Aeronautics, Exploration and Technology
National Aeronautics and Space Administration

OUTLINE

- PROGRAM GOALS
- TECHNICAL OBJECTIVES/PROGRAM DESCRIPTION
- JUSTIFICATION
- STATE OF THE ART ASSESSMENT
- TECHNOLOGY INTERFACES
- PAYOFF
- DELIVERABLES
- APPROACH
- SCHEDULE
- RELATIONSHIP TO EXTERNAL PROGRAMS

PROGRAM GOAL

INCREASE THE EFFECTIVENESS AND EFFICIENCY OF SCIENTISTS TO EXTRACT SCIENTIFIC INFORMATION FROM LARGE VOLUMES OF INSTRUMENT DATA

- SHORTEN THE TIME BETWEEN "DATA TAKING" AND SCIENTIFIC RESULT
- EFFICIENT INTEGRATION AND ANALYSIS OF MULTIPLE DATA FROM DISPARATE SOURCES IN A COMPLEX MODEL SETTING
- ENHANCE THE PROSPECT FOR "DISCOVERY"

DSCS — VISUALIZATION — DATA SYSTEMS & COMPUTER SCIENCE

TECHNICAL OBJECTIVES

Develop technology for automated characterization, and interactive retrieval and visualization for very large, complex scientific data sets

- TO DEVELOP AN INTEGRATED FAMILY OF TOOLS, PROCEDURES AND VISUALIZATION ENVIRONMENTS FOR INTERACTIVELY VISUALIZING SCIENCE DATA, AND MERGING AND COMPARING THE DATA WITH SCIENCE MODELS
  - INTERACTIVE NAVIGATION OF OBSERVED AND MODELED DATA
    - 10-30 512 × 512 FRAMES/SEC
    - INTERACTIVE FLIGHT PATH, VIEWING ANGLE CONTROL, TOOLS FOR FLIGHT PATH DESIGN
    - INTERACTIVE INTERROGATION OF RELATED DATA
  - INTERACTIVE SIMULATION FOR MISSION/INSTRUMENT DESIGN: TOOLS AND PROCEDURES THAT PROVIDE THE ABILITY TO SIMULATE MISSIONS, INSTRUMENT PERFORMANCE AND OBSERVATIONAL ENVIRONMENTS IN AN INTERACTIVE USER ENVIRONMENT
    - DYNAMIC SIMULATION OF PHYSICAL PHENOMENA
    - SIMULATION OF INSTRUMENT/SENSOR PERFORMANCE
    - SIMULATION OF MISSION DATA ACQUISITION MODALITIES
    - MERGE AND COMPARE MODELS AND OBSERVABLES

TECHNICAL OBJECTIVES (Cont'd)

- INTERACTIVE USER INTERFACE
  - DEVELOP INTERACTIVE PRINCIPLES THAT ARE EFFECTIVE FOR SCIENCE USER INTERACTION WITH 3D DATA
  - DESIGN, PROTOTYPE AND EVALUATION OF VIRTUAL REALITY BASED USER INTERFACES
  - DESIGN, PROTOTYPE AND EVALUATION OF GRAPHICALLY ORIENTED USER INTERFACE
  - INTEGRATION OF USER INTERFACE MODALITIES

DSCS — VISUALIZATION — DATA SYSTEMS & COMPUTER SCIENCE

TECHNICAL OBJECTIVES (Cont'd)

- VISUALIZATION TECHNOLOGY RESEARCH CENTER: IMPLEMENT A SEQUENCE OF WORKSTATION BASED/HIGH RESOLUTION DISPLAY CONFIGURATIONS THAT PROVIDE AN EXPERIMENTAL ENVIRONMENT
  - INTERFACE TO HIGH PERFORMANCE NETWORKS SUCH AS CASA, NREN (HPCC)
  - ACCESS HIGH PERFORMANCE COMPUTING SUCH AS THE INTEL DELTA (CALTECH) AND THE HIGH PERFORMANCE COMPUTING SYSTEMS (HPCC)
  - QUERY AND ACCESS DATA FROM THE MASS STORAGE TESTBED

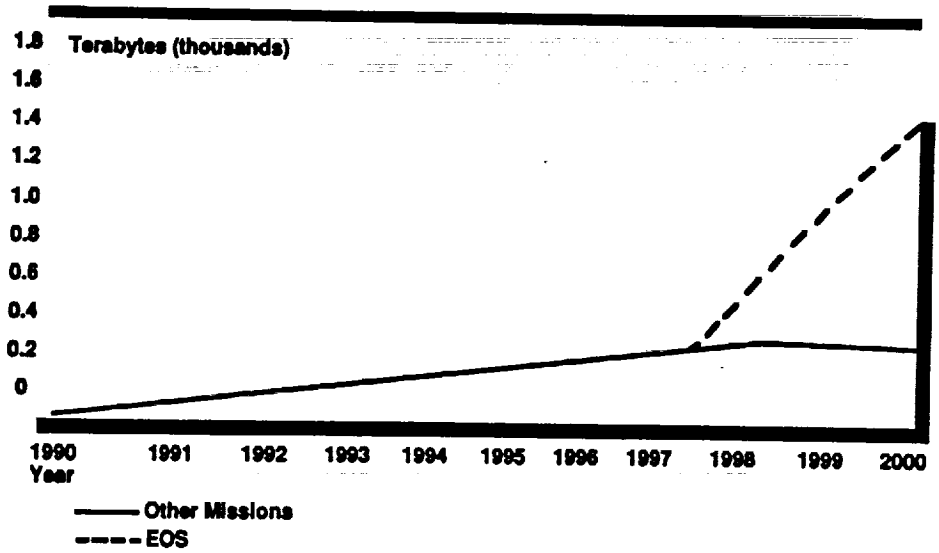
JUSTIFICATION

- FUTURE PROGRAMS IN EARTH SCIENCES, PLANETARY SCIENCES AND ASTROPHYSICS INVOLVE COMPLEX INSTRUMENTS THAT PRODUCE DATA AT UNPRECEDENTED RATES AND VOLUMES. CURRENT TECHNOLOGY FOR DATA DISPLAY, EXPLORATION AND SCIENCE DISCOVERY ARE INADEQUATE

- VISUALIZATION TECHNOLOGY OFFERS THE MEANS FOR THE SCIENCE USER TO COMPREHEND, EXPLORE AND EXAMINE THIS DATA TO FOCUS FURTHER ANALYSIS AND PROVIDE INSIGHTS INTO ANALYSIS GOALS AND PROCESSES

DSCS — VISUALIZATION — DATA SYSTEMS & COMPUTER SCIENCE

JUSTIFICATION



TECHNOLOGY CHALLENGES

- DEVELOPMENT OF AN INTERACTIVE FAMILY OF TOOLS, TECHNIQUES AND PROCEDURES FOR OBSERVING SCIENCE INSTRUMENT DATA THAT DISPLAY SPATIAL, TEMPORAL, AND SPECTRAL RELATIONSHIPS IN A MANNER THAT EXPLOITS HUMAN COGNITIVE SKILLS
- TAKING ADVANTAGE OF THE COMPUTING CAPABILITY OFFERED BY CONCURRENT COMPUTING ARCHITECTURES
- INCORPORATING BEHAVIORAL SCIENCE TECHNOLOGY TO REDUCE COMPUTATIONAL REQUIREMENTS IN VIRTUAL REALITY
- DESIGNING OF THE USER INTERFACE TO PROVIDE EFFECTIVE ERGONOMICS AND SIMPLE PROCEDURES FOR PRODUCING DATA VISUALIZATIONS
- PROVIDING FOR INTERACTIVE EXAMINATION, VARIATION AND VALIDATION OF SCIENTIFIC MODELS IN A REAL DATA ENVIRONMENT

STATE OF THE ART ASSESSMENT

PROGRAM ELEMENT	TODAY	TARGET
• INTERACTIVE NAVIGATION	• TECHNOLOGY TO GENERATE "PRE-PLANNED" ANIMATIONS • RENDERING SPEEDS FOR 512 X 512 FRAMES (30 PERSPECTIVE) ARE TENS OF SECONDS	• CAPABILITY TO INTERACTIVELY NAVIGATE 3D DATA AT NEAR VIDEO RATES FOR NTSC CLASS FORMATS
• INTERACTIVE SIMULATION	• NO INTERACTIVE CAPABILITY • LIMITED MISSION SIMULATION CAPABILITY, MISSION SPECIFIC • SENSOR/INSTRUMENTS NOT INCORPORATED • ABILITY TO MODEL AND SIDPLAY • NO INTERACTIVE CAPABILITY	• CAPABILITY TO SIMULATE MISSION, INSTRUMENT PERFORMANCE WITH INTERACTIVE VARIATION. • INTERACTIVE MERGE AND COMPARE MODELS AND OBSERVATIONS
• INTERACTIVE USER INTERFACE	• GUI'S EXIST THAT PROVIDE PROCESSING LINKS AND PARAMETER SELECTION • GUI'S EXIST THAT ALLOW USER TO MANIPULATE SOURCE DATA AND SEE RESULTS IN RENDERED VIEW. • VIRTUAL REALITY WITH LIMITED DISPLAY (250 X 250) AND LIMITED TRACKING	• INTERACTIVE GUI FOR END-TO-END MANAGEMENT AND MANIPULATION • VIRTUAL REALITY INTERFACE WITH SATISFACTORY VISUAL RESOLUTION AND MOTION RESPONSE

PAYOFF

- EFFECTIVE DATA INTERPRETATION: SPATIAL RELATIONSHIPS, DYNAMIC PROCESSES, DATA STRUCTURES AND MORPHOLOGIES MORE EFFECTIVELY PERCEIVED VISUALLY. GOOD VEHICLE FOR DISCOVERY
- EFFICIENT DATA REDUCTION: PROVIDES ABILITY TO VIEW AND ANALYZE LARGE VOLUMES OF DATA FASTER
- EASE OF DATA REDUCTION: EASIER, MORE USER ATTRACTIVE METHODS OF DATA REDUCTION
- EFFICIENT DATA ACQUISITION: BETTER MISSION PLANNING, SELECTIVE DATA ACQUISITION
- PUBLICLY ENGAGING PRODUCTS: VIDEOS, ANIMATIONS AND OTHER VISUALIZATION PRODUCT FORMATS ARE EASIER FOR PUBLIC TO COMPREHEND. STIMULATES SCIENCE INTEREST AND PRODUCES POSITIVE PUBLIC SUPPORT FOR NASA PROGRAMS

DELIVERABLES

1997

- CAPABILITY TO INTERACTIVELY NAVIGATE 3D DATA AT NEAR VIDEO RATES FOR NTSC CLASS FORMATS
- CAPABILITY TO SIMULATE MISSION, INSTRUMENT PERFORMANCE, INTERACTIVE VARIATION OF TRAJECTORIES, SENSOR/INSTRUMENT PARAMETERS. MERGE AND COMPARE PHENOMENOLOGICAL MODELS AND OBSERVABLES
- INTERACTIVE INTEGRATED USER INTERFACE
- WORKSTATION/HIGH RESOLUTION BASED CONFIGURATION INTERFACED TO HIGH PERFORMANCE COMPUTING RESOURCE WITH ABILITY TO ACCESS THE MASS STORAGE TESTBED

DELIVERABLES

- CONCURRENT ALGORITHMS AND SOFTWARE FOR RENDERING MODELING, MAPPING, MERGING, ETC.
- VISUALIZATION COMPUTING ENVIRONMENT SOFTWARE
- USER INTERFACE SOFTWARE
- WORKSTATIONS AND ASSOCIATED PERIPHERALS INCLUDING HIGH RESOLUTION DISPLAYS AND VIDEO GENERATION HARDWARE VIRTUAL REALITY HARDWARE
- DATABASES
- TECHNOLOGY PLAN, DEMOSTRATIONS, REPORTS, PAPERS

DSCS — VISUALIZATION — DATA SYSTEMS & COMPUTER SCIENCE

DELIVERABLES

(FACING PAGE)

1991	1995	2000	2005
• PRE CAST ANIMATIONS	• REAL TIME ANIMATIONS WITH I/A 'STEERING' THROUGH MULTISPECTRAL, 3D DATA BASES WITH LIMITED RESOLUTION	• R/T ANIMATIONS WITH ADDED FUNCTION E.G. ANCILLARY DATA ACCESS, FEATURE EXTRACTION ETC. EXTENDED RESOLUTION	• R/T ANIMATIONS WITH FULL USER CONTROLLED FUNCTION. WORKSTATION ENVIRONMENT
• ENVIRONMENT SPECIFIC SYSTEMS	• LIMITED INTEROPERABILITY • WS I/F TO HIGH SPEED NETS ACCESS TO COMPUTING	• MUCH IMPROVED INTEROPERABILITY • WS I/F TO HIGH SPEED NETS; FULL ACCESS TO REMOTE RESOURCES	• TRANSPARENT OBJECT ORIENTED VISUALIZATION ENVIRONMENTS THAT ALLOWS CORRELATING MULTIPLE DATA BASES SUPPORTING GEOGRAPHICALLY SEPARATE USERS
• BATCH, INTERACTION ON DISPLAY ONLY	• LIMITED MODEL INTERACTION E.G. MODIFYING, COMPARING AND ADJUSTING	• IMPROVED MODEL BUILDING TOOLS, INTERACTION AND CONTROL	• GENERAL I/F TO HIGH SPEED NETS; FULL SPECTRUM OF TRANSPARENT RESOURCE MANAGEMENT
• SYSTEM OPERATED BY SPECIALIST, NOT END USER	• LIMITED GRAPHICAL USER INTERFACES • LIMITED VIRTUAL USER ENVIRONMENTS	• GENERALIZED GRAPHICAL USER INTERFACES • MATURE VIRTUAL USER ENVIRONMENTS FOR SPECIALIZED APPLICATIONS	• PORTABLE, ROBUST GENERALIZED GUI SUPPORTING DATA ACCESS, AND FULL RANGE OF CONSTRUCTIONS AND INTERACTIONS
	• SPECIALIZED WORK STATION TOOLS, TECHNIQUES FOR CREATING VISUALIZATIONS	• GENERAL WORKSTATION VISUALIZATION CAPABILITY	• ERGONOMICALLY CORRECT VIRTUAL ENVIRONMENTS

APPROACH

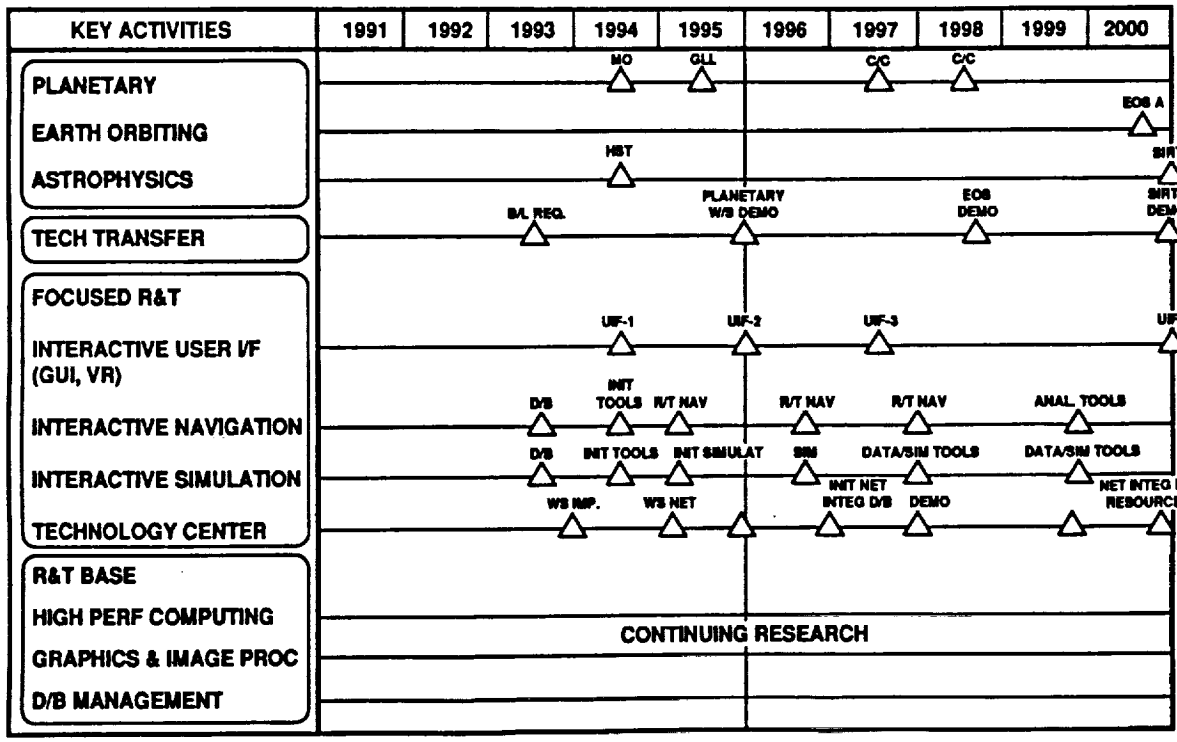
- TARGET NASA HIGH RATE INSTRUMENTS
- WORK WITH DISCIPLINE SCIENTISTS
- UTILIZE CONCURRENT COMPUTING
- LEVERAGE OTHER RESEARCH PROGRAMS AND THE COMMERCIAL SECTOR

DSCS — VISUALIZATION — DATA SYSTEMS & COMPUTER SCIENCE

APPROACH (Cont'd)

- EMBED METHODOLOGY IN COMMON SOFTWARE ENVIRONMENTS SUPPORTED BY PLATFORMS ACCESSIBLE BY A MAJORITY OF THE SCIENCE COMMUNITY
- CONCENTRATE ON TOOLS AND TECHNIQUES FOR MANAGING AND IMPLEMENTING VISUALIZATIONS AND DISPLAYS. DEVELOP INTERFACES AND REQUIREMENTS FOR SUPPORTING ELEMENTS
- PRODUCE A SEQUENCE OF TRANSFERABLE CAPABILITY

SCHEDULE



RELATIONSHIP TO OTHER PROGRAMS

HIGH PERFORMANCE COMPUTING AND COMMUNICATIONS HPCC PROGRAM

- TESTBED CONCEPT IS CONSISTENT WITH THE HPCC ADVANCED WORKSTATION, HIGH RESOLUTION DISPLAY CONCEPT
- SUPPORT EVALUATION OF EARLY COMPUTING SYSTEMS AND ADVANCED PROTOTYPE SYSTEMS VIA NATIONAL RESEARCH AND EDUCATION NETWORK (NREN)
- CONTRIBUTE TO THE SOFTWARE COMPONENTS AND TOOLS ELEMENT OF THE ADVANCED SOFTWARE TECHNOLOGY AND ALGORITHMS (ASTA) COMPONENT OF THE HPCC

NATIONAL SCIENCE FOUNDATION

- NSF FUNDED WORK IN COMPUTATIONAL FLUID DYNAMICS AND IN GENERAL VISUALIZATION OF MODELS WILL PROVIDE A VALUABLE STARTING POINT FOR THE WORK IN MISSION SIMULATION

RELATIONSHIP TO OTHER PROGRAMS (Cont'd)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

- INFORMATION SYSTEMS RESEARCH AND ANALYSIS (SMI): THIS WORK WILL BUILD ON THE ANIMATION, GRAPHICS AND ANALYSIS TECHNIQUES DEVELOPED WITHIN THIS PROGRAM ELEMENT
- SCIENCE COMPUTING (SMI): THIS WORK WILL BUILD ON ALGORITHMS AND SOFTWARE DEVELOPED IN THE CONCURRENT IMAGE PROCESSING TESTBED (CIPT)

External Review of the
Integrated Technology Plan for the Civil Space Program

DATA SYSTEMS & COMPUTER SCIENCE

Software Engineering Program

Arthur I. Zygielbaum

JPL

June 26, 1991

Office of Aeronautics, Exploration and Technology
National Aeronautics and Space Administration

Program Goals

Improve NASA's ability to manage development, operation, and maintenance of complex software systems

- Predict and monitor development cost and schedule
- Predict operations costs and impacts to users
- Identify, adopt, and/or adapt product and process metrics
- Recommend prescriptive actions appropriate to symptoms indicated by metrics
- Focus: ***Improve the process maturity of NASA software development efforts***

Decrease NASA's cost and risk in engineering complex software systems

- Improve ability to specify functionality and assure delivered functionality
- Provide mechanisms to aid in requirements discovery, and the subsequent development and tracking of specifications
- Provide technology to create, identify, archive, and access reusable parts
- Assure that software can be evolved to run on improved, upgraded, and/or more cost-effective hardware

Provide technology to assure safety and reliability of software in mission critical applications

- Develop formal approaches to software development & maintenance
- Build tools, methodologies, and standards for constructing software architectures for fault containment and recovery

Program Goals

DSCS — DATA SYSTEMS & COMPUTER SCIENCE

- **Improve NASA's ability to manage development, operation, and maintenance of complex software systems**
  - Focus: ***Improve the process maturity of NASA software development efforts***
- **Decrease NASA's cost and risk in engineering complex software systems**
- **Provide technology to assure safety and reliability of software in mission critical applications**

2

Rationale

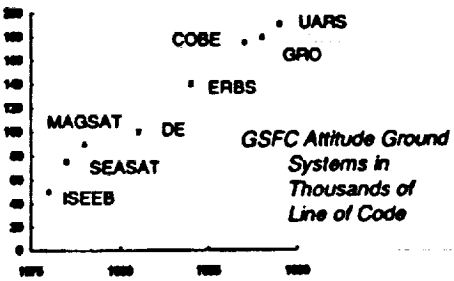
DSCS — DATA SYSTEMS & COMPUTER SCIENCE

NASA's need for software

Software development represents between 10 and 20% of NASA's budget directly

Software development influences or is critical to the success of 80% of NASA's programs and projects

NASA's software investment is growing substantially



New emphasis on long-term observation missions like EOS require economical, efficient, operable, and easy-to-maintain software

Studies indicate demand growth is still increasing faster than supply growth (Software Engineering Institute, National Research Council, Aerospace Industries Association)

Software represents a development risk for NASA programs and projects

E.g., DSN and Shuttle have had significant cost growth and delayed or "descoped" deliveries due to software difficulties

Need to ameliorate cost and risk

Need for mechanisms for software engineering and management technology information exchange, transition, and insertion

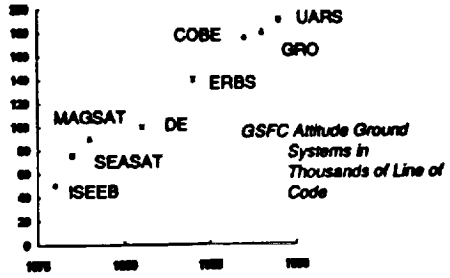
3

C-2

Rationale

NASA's need for software

- Software is now approx 20% of NASA budget
- Software affects 80% of NASA's programs



- **Software represents a development risk for NASA programs and projects**
- **Need to ameliorate cost and risk**
- **Need for mechanisms for software engineering and management technology information exchange, transition, and insertion**

3

Technology Challenges

NASA's "Tall Poles" in software

Software is extremely complex, frequently real-time

Systems are interdependent and distributed

System longevity is great

- **Probes to planets for long-term exploration**
- **Earth satellites with decade missions**

Reliability is especially important due to man-rating, cost risk, and/or visibility

- ***Software must be fail-safe in many cases***

JPL experience:

Moving from SEI level 1 to 2 on a particular project led to 50% more productivity

Software technology levels

Today	Need	Challenge
Most Centers SEI Level 1 to 2	SEI Level 4 to 5	Upgrade management and engineering capability without increasing cost
Some software at SEI Level 4 to 5 e.g. Shuttle flight: 1.8 Lines of Code/Day	SEI Level 5 at 20 lines of code per day per person	Increase productivity without decreasing process maturity level
Facing high software cost growth factor i.e. Shuttle: Factor of 20	Control growth and cost 0 cost growth	Ability to manage and engineer

4

Technology Challenges

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Facing high software cost growth factor i.e. Shuttle: Factor of 20	Control growth and cost 0 cost growth	Ability to manage and engineer

Program Description

Elements of Program (1)

Assess and Support NASA Software Engineering Infrastructure

Establish a permanent software technology assessment and transition office in concert with Code Q and managed through a coordination council having representatives from Codes R, S, O, M, etc.

Focus the program to develop technology, methods, and tools to measure the effectiveness of all parts of software development infrastructure:

tools, management, quality assurance, etc.

Support both software development and software acquisition

Improve Software Process Technology and Engineering

Develop methods to instrument the development process

Determine empirically the impact of product and process standards, paradigms, and/or tools and recommend appropriate improvements to them

Develop the technology to decrease the cost and risk involved in "overhead" functions such as configuration management and document development

Identify and develop tools that aid in systems engineering. These include tools for the total system which allow for the modeling of software as part of a large system and tools to aid in requirements discovery, specification development, and assurance of both process and product performance

Specifically develop tools, methods, technologies, etc., which support reuse of software

Elements of Program (1)

Assess and Support NASA Software Engineering Infrastructure

- Permanent software technology assessment and transition office
- Measure effectiveness of software infrastructure
- Support acquisition and development

Improve Software Process Technology and Engineering

- Instrument the development process
- Empirical process impact determination
- Decrease the cost and risk involved in "overhead" functions
- Identify and develop tools that aid in systems engineering.

Elements of Program (2)

Support the "Renewal" of Software Systems:

Facilitate adapting to changes in technology, standards, methodology, techniques, etc.

Develop or adapt technology which allows evolutionary movement of software among computer manufacturers.

Develop or adapt technology which allows for in-situ software upgrading without interruption of critical systems.

Develop or adapt technology which aids in configuration management in distributed systems as those systems are being upgraded and tested.

Develop or adapt mechanisms to certify software on new platforms and devices

Software Process Management

Develop or adopt technologies, tools, methods, etc. which provide touchstones to indicate the status of particular software efforts, which provide indicators to suggest corrective action, and which allow easy correlation between requirements and resulting costs and risks.

Elements of Program (2)

Support the "Renewal" of Software Systems:

- Adapt to change
- Facilitate evolutionary movement of software
- Enable in-situ software upgrading without interruption of critical systems.
- Facilitate configuration management in distributed systems
- Certify software on new platforms and devices

Software Process Management

- Provide management touchstones

Schedule

- **1993**

  Start software metrics program in NASA domains: manned flight, unmanned flight, and large ground data systems

- **1994**

  Begin advanced tool development for reuse, reliability assessment, risk management, software development process control and renewal

- **1995**

  Complete quality assessments (productivity, reliability, maintainability in identified domains

- **1996**

  Begin to insert advanced tools and procedures in domains being supported on non-interfering basis

- **1997**

  Assess impact of advanced technology using metrics program

Schedule

- **1993** Start software metrics program
- **1994** Begin advanced tool development
- **1995** Complete quality assessments
- **1996** Begin to insert advanced tools and procedures
- **1997** Assess impact of advanced technology

7

Relationship to Other Programs (1)

Existing and candidate external programs for partnerships with NASA to develop new technologies, methods, and tools, and to transition these new technologies into practice

Within NASA

Code Q's Software Management and Assurance (SMAP) Program

NASA organizations developing software applications to develop technology and assess its impact

Langley's Aeronautics Program to develop formal methods and highly robust software

Other Government Organizations

DoD's Software Technology for Adaptable Reliable Systems (STARS) Program to develop more powerful, reliable and adaptable mission - critical software

Universities

Universities to collaborate with NASA to develop new technologies and test them in NASA software development environment

e.g., Goddard's Software Engineering Laboratory (SEL) collaboration with the University of Maryland

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Relationship to Other Programs (1)

Existing and candidate external programs for partnerships with NASA to develop new technologies, methods, and tools, and to transition these new technologies into practice

Within NASA

- Code Q's Software Management and Assurance (SMAP) Program
- NASA software development organizations
- Langley's Aeronautics Program

Other Government Organizations

- DoD's Software Engineering Institute
- DoD's STARS program

Universities

Collaborations to for R&D

Relationship to Other Programs (2)

Commercial Consortiums

- Software Productivity Consortium (SPC) of aerospace member companies to develop technology, methods, and supporting tools and services that improve quality and productivity in the development of software systems to meet end user's needs
- Microelectronics and Computer Technology Corporation (MCC), a consortium of competitive companies cooperating on large scale pre-competitive research, to leverage R&D work and transition new technology into practice
- Research Triangle Institute has had a long-term relationship with NASA Langley

DoD's Software Engineering Institute (SEI), the technology transition arm of STARS, to validate emerging technologies and bring them into practice

- Alternate Learning Technology Beta test site
- SEI process maturity assessments
- Audit formal inspection process for SEI Levels 4-5

Relationship to Other Programs (2)

Commercial Consortiums

- Software Productivity Consortium (SPC)
- Microelectronics and Computer Technology Corporation (MCC)
- Research Triangle Institute

DoD's Software Engineering Institute (SEI)

9

ISSUES

NASA should collaborate with external programs, not wait to buy the technology from them:

NASA needs real-time, highly reliable and safe systems that must perform correctly the first time

Industry must produce a profit through producing high volumes of a system

NASA must produce one-of-a-kind systems cost effectively

Focus Program is not possible at $1.1B funding level in RC Technology

>50% budget cut

forces base program to pick up developing technology to greater readiness levels at expense of further research

eliminates or stretches out by years many proposed focussed tasks

Need for partnerships for coordination and technology transition

reach out to industry impossible except informally with current base funding

10

ISSUES

DSCS — DATA SYSTEMS & COMPUTER SCIENCE

NASA should collaborate with external programs

Focus Program is not possible at $1.1B funding level in RC Technology

Need for partnerships for coordination and technology transition

10

Summing Up

DSCS — DATA SYSTEMS & COMPUTER SCIENCE

This program is Advanced Research and Technology to improve development, operations, and maintenance of complex, reliable software.

A means to improve NASA's ability to develop complex software systems using enhancing and enabling technology

A mechanism to provide the tools and expertise to validate process and paradigm decisions.

A research agenda to develop basic precepts, methods, and tools to improve the software development, maintenance, and management infrastructure of NASA.

A mechanism to transfer new technology, techniques, etc., into practice through the "doing" organizations.

A means to ensure that the cost of doing software (acquiring, developing, maintaining, managing) is not a driver in Mission Operations and Data Analysis systems.

This program provides tools, methods, technology, and knowledge to allow Code Q to set better software assurance and life cycle standards, and other codes to be more efficient and effective in developing software.

11

Summing Up

- This program is Advanced Research and Technology to improve development, operations, and maintenance of complex, reliable software.

- This program provides tools, methods, technology, and knowledge to allow Code Q to set better software assurance and life cycle standards, and other codes to be more efficient and effective in developing software.

11

Summing Up

DSCS — DATA SYSTEMS & COMPUTER SCIENCE

- This program is Advanced Research and Technology to improve development, operations, and maintenance of complex, reliable software.

- This program provides tools, methods, technology, and knowledge to allow Code Q to set better software assurance and life cycle standards, and other codes to be more efficient and effective in developing software.

11

MULTI-MISSION OPERATIONS TESTBED

Paul Messina
David Curkendall

Jet Propulsion Laboratory

June 26, 1991

Office of Aeronautics, Exploration and Technology
National Aeronautics and Space Administration

PROGRAM GOALS

OPERATIONS

- Develop Technology To Enable Future Mission Operations Centers to Support Multiple Missions, Each With Orders of Magnitude Greater Science/Telemetry Bandwidths and Subsequent Data Processing Demands.
- Reduce By An Order Of Magnitude the Time Required To Develop and Generate Sequences For Complex Spacecraft.
- Develop the Techniques and Systems Required To Perform Detailed S/C Sequence Simulation in 10X Real Time.
- Provide the Techniques Required For Quick Look Scientific Data Analysis For Future Missions Such As EOS SAR.
- Develop A Set Of Coherent Techniques For The Detection (Through Quick Look Capabilities) and Exploitation (Via Instant Sequencing) of Unforseen Phenomena.

JUSTIFICATION

OPERATIONS

- Future Missions Sequence Complexity and Downlink Data Bandwidths Produce Demands On Mission Operations That Cannot Be Met With Current Technology. Examples:
  - EOS SAR Quick Response Time Line Requirements Cannot Be Met.
  - Mission Ops Has Declared That Expected Scientific Mission Return From CRAF/CASSINI Is Unrealistic Because Of Mission Ops Constraints.
- Sequence Generation Complexity Grows As Factorial(N!) of the Number of S/C Instruments, N.
- Modern Instruments Such as SAR and TESS Require Access To Orders of Magnitude More Computational Processing Power For Real Time Instrument Calibration And Quick Look Analyses.
  - For First Time, Require Real Time SuperComputer Computations

SOME JPL SENTIMENTS FROM THE FRONT LINES

OPERATIONS

F. L. Jordan - Manager, Systems Division

The uplink is the real problem when operation of complex spacecraft is involved. It's been ignored in R&D funding for at least 10 years. The right combination of computer technology and advanced applications systems engineering can bring us into the modern world. But how do you do that with dollars only to solve this year's problems?

N. R. Haynes - Deputy ALD for Flight Projects

The Flight Projects are constantly put in the position of developing the bare essentials for Ops on a Project by Project basis. We desperately need some Code R help that can take a long range, Multi-Mission view.

M. J. Sander - Manager EOS SAR Project

There have been major improvements in accommodating increases in downlink complexity but low cost operations have never had the R&D base which would allow substantial *real* improvements. Lots of talk, no support. Long lifetime missions such as EOS SAR will require $6M real year dollars per 40hr/wk operations.

continued.....

MORE JPL SENTIMENTS FROM THE FRONT LINES

OPERATIONS

P. E. Doms - Manager, Ground Data System, CRAF/CASSINI P

The expected scientific return from CRAF/CASSINI cannot be delivered because of constraints in the Mission Ops Control.

T. D. Linick - Manager, Flight Project Support Office

Flight Ops is nearly as big a slice of the Flight Project budget pie as is the flight system itself. Yet we have not made a significant R&D investment in this area in 25 years. Such an investment now will not only pay performance dividends, it can significantly reduce overall operations costs.

PROGRAM DESCRIPTION

OPERATIONS

- The program will create a test bed for exploring the use of new technologies in mission control centers and for developing new technologies as needed. Key applications will be targeted, especially command sequence generation and validation, spacecraft simulation, quick-look capability, and science databases.

- Payoff will be ability to design and deploy future mission operations centers that enable missions to produce more scientific results with fewer resources.

- Deliverables include scalable parallel algorithms for command sequence generation and validation, prototype integrated software environment, design criteria and configuration guideline for scalable multi-mission operations centers, prototype data management system, network technology for congestion-resistant, fault-tolerant computer networks.

TECHNOLOGY CHALLENGES

OPERATIONS

- Developing efficient parallel algorithms for command sequence checking and spacecraft simulation.
- Developing uniform access to distributed databases to facilitate transfer of analysis data between teams, subteams, and analysts.
- Creating an integrated environment for multiple missions with compatible or identical analysis tools, displays, data retrieval methods, etc., and with scalability in processing and data rates.
- Creating visually-oriented system for specifying science requirements that lead to command sequences and further automating the planning of multiple science activities.
- Integrating multiple networks with different speed and protocols (HIPPI at 800 Mbps, FDDI at 100/200 Mbps, custom at 400 Mbps) while ensuring robustness, scalability, security, and reliability.

STRATEGIC PLAN: Technology Development

TECHNOLOGY AREA	STATE-OF-THE-ART	TARGETS
Mission Ops Technology.		
Networks	• Multiple Ethernet LAN's, 10mbits/sec	• 1 Gb/sec Multi-Channel Transfer Rate • Global F. T. Network • High Speed H/W Routing • All Fiber Optic
Database	• Centralized Relational Databse	• Distributed Object Oriented D. B. • 1 Terabyte Online Storage • 1 Terabyte/ Day Mass Storage
Applications Technology	• Loosely Connected Disparate Sub-Operations • Quick Look Computations On Vax Networks and Remote Mainframes • Batch Processing Characterizes Most Operations	• Instant Sequencing • Real Time Quick Look/Calibration • Adaptive Sequencing Responsive To Quick Look Phenomenon Discoveries • Seamless Applications Integration
Environment	• Unix TCP/IP, SQL Database	• Merger of Network Computing and Parallel Processing

RELATIONSHIP TO EXTERNAL PROGRAMS

OPERATIONS

- Builds on parallel computing work done at JPL and many other institutions, such as discrete-event simulation.
- Builds on technology developed for military command centers.
- Makes selective use of products of HPCCP for compute-intensive tasks
- Has unique characteristics due to duration of missions, timing requirements.
- Builds on on-going program at GSFC in object oriented data bases.

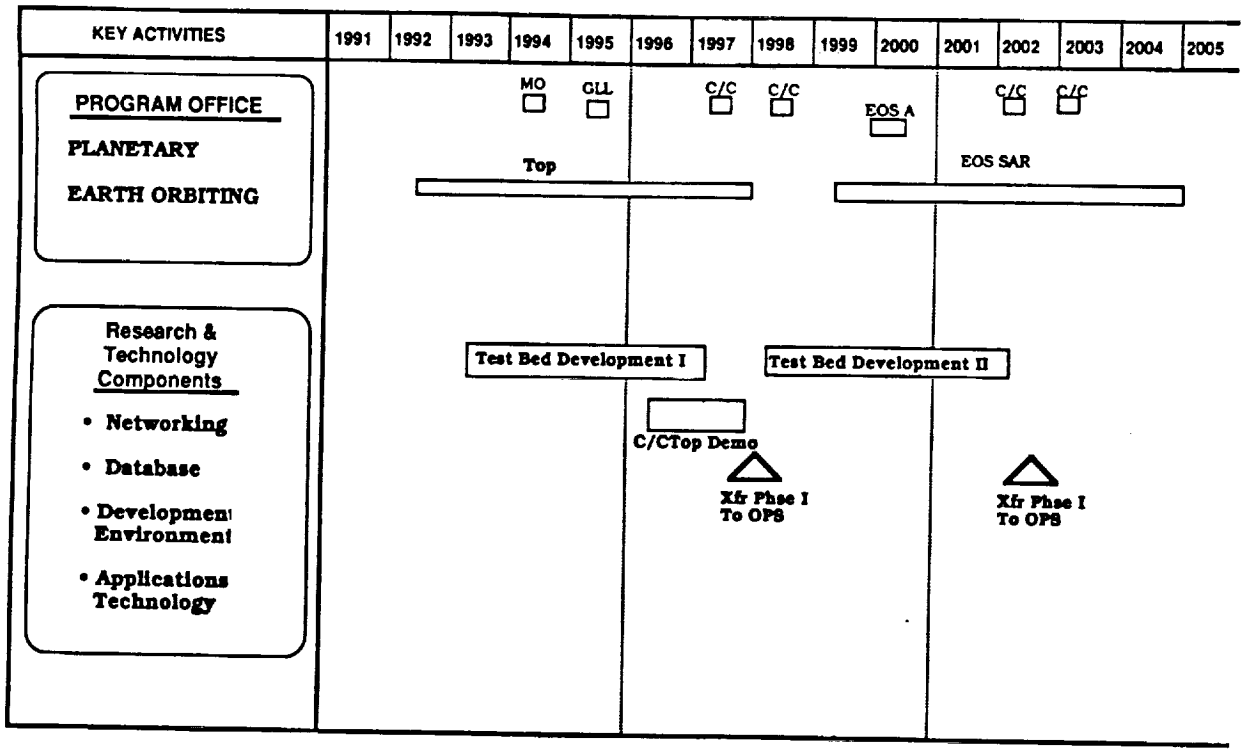
TECHNOLOGY DEVELOPMENT APPROACH

OPERATIONS

- Team computer technologists, mission planners, and science community for requirements definition.
- Determine system architecture and advanced computer technologies for Test Bed System. Modest workstation and network component procurements.
- Enhance JPL's parallel programming software and merge with industry supplied network computing interface. Use GSFC's Object Oriented Database as point of departure for distributed, fault tolerant, multi-media database.
- Develop parallel, high performance versions of sequence generation and verification, science intstrument data quick-look and other applications.
- Demonstrate capabilities in real time on C/C and extended Topex Missions.
- Transfer first version to operations for support of CRAF and EOS SAR.

DEVELOPMENT ROADMAP

OPERATIONS



KEY ISSUES

OPERATIONS

- This Initiative Is Currently Not Funded.
- Integration and Utilization of advanced technologies is very slow unless someone takes risks.

SSTAC Review of the
Integrated Technology Plan for the Civil Space Program

DATA SYSTEMS & COMPUTER SCIENCE

NEURAL NETWORKS BASE R&T PROGRAM OVERVIEW

Sandeep Gulati
Center for Space Microelectronics Technology
Jet Propulsion Laboratory

June 26, 1991

TECHNICAL OBJECTIVES

Develop and demonstrate adaptive, neural information processing concepts (leveraging external funding)

- massively parallel (1024 neurons ; 10^6 synapses per chip), synchronous fast reconfigurable (< 1ms electronic, < 1μs optical loading), 10^{13} ops/s, neuroprocessors to
  - achieve at least 100X speedup over SOA supercomputers for ground-based, simulation of complex phenomena modeled by PDEs (e.g., planetary geophysics)
  - achieve 100X - 1000X speedup during onboard, large-scale science data reduction
- concurrently asynchronous, reprogrammable, nonvolatile, analog neural processors with high speed, high BW electronic/optical I/O interfaces to
  - enable inflight resource allocation and diagnostic analysis
  - enhance guidance / landing precision and stability, using thruster / velocity control for hypersonic aircraft / spacecraft
    - integrated neural controllers / flight simulators

NEURAL NETWORKS BASE R&T

DSCS — DATA SYSTEMS & COMPUTER SCIENCE

TECHNICAL OBJECTIVES

Develop and demonstrate adaptive, neural information processing concepts

- synchronous, fast reconfigurable neuroprocessors to
  - achieve at least 100X speedup for ground-based, simulation of complex science phenomena , e.g., planetary geophysics
  - achieve 100X - 1000X speedup during onboard, large-scale science data reduction
- concurrently asynchronous, reprogrammable, analog neural processors
  - enable inflight resource allocation & diagnostic analysis
  - enhance guidance / landing precision and stability for hypersonic aircraft / spacecraft

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JUSTIFICATION

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- **Potential for significant on-board processing improvements**
  - 100X to 10000X speedup over SOA supercomputers / special purpose processors
    - signal processing, geophysical / aerodynamic modeling, resource allocation etc.
  - adaptive (e.g., on-line trainable processors) with long life-times
  - ultra-fast reconfigurability (<1ms electronic, < 1μs with optical loading)
  - inherently fault-tolerant
  - power, weight and size stringent
- **Potential for improved control precision in complex, nonlinear regimes**
  - facilitate qualifiability for spaceflight control systems operating outside boundary conditions certified using conventional control formalisms
  - control at flight speeds surpassing human response times

JUSTIFICATION

- **Potential for significant on-board processing improvements**
  - 100X to 10000X computational speedup
  - ultra-fast reconfigurability
  - inherently fault-tolerant
  - power, weight and size stringent
- **Potential for improved control precision in complex, nonlinear regimes**
  - facilitate qualifiability
  - surpass human response times at flight speeds

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TECHNOLOGY CHALLENGES

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- **Ultracompact packaging of high-density nonvolatile, analog devices (e.g., thin film switches, ferroelectric devices)**
  - long term time and temperature stability (processors based on electrochemical composite devices)
  - addressability and I/O at ultra-high bandwidths
- **High precision computing using low precision (typically 8-14 bits) components**
  - hyperacuity / computing using neural oscillators
- **"Noise" in massively parallel neural systems**
  - "emergent" computation chaos due to concurrent asynchronicity
  - inherent device noise (e.g., crosstalk, op-amp offset, switched capacitors)
- **High-bandwidth interfacing with convential digital systems and sensor arrays**
- **Reliability under spaceflight conditions**
  - formal ("algorithmic") verification of system performance
  - "cell damage" in non-attractor type computations
- **Capture of human non-linear control behaviors in noisy environments**
  - ill-defined boundary conditions

TECHNOLOGY CHALLENGES

- Ultracompact packaging
- High precision computing using low precision components
- "Noise" in massively parallel neural systems
- High-bandwidth interfacing with convential digital systems
- Reliability under spaceflight conditions
- Capture of human non-linear control behaviors

NEURAL NETWORKS BASE R&T
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DATA SYSTEMS & COMPUTER SCIENCE

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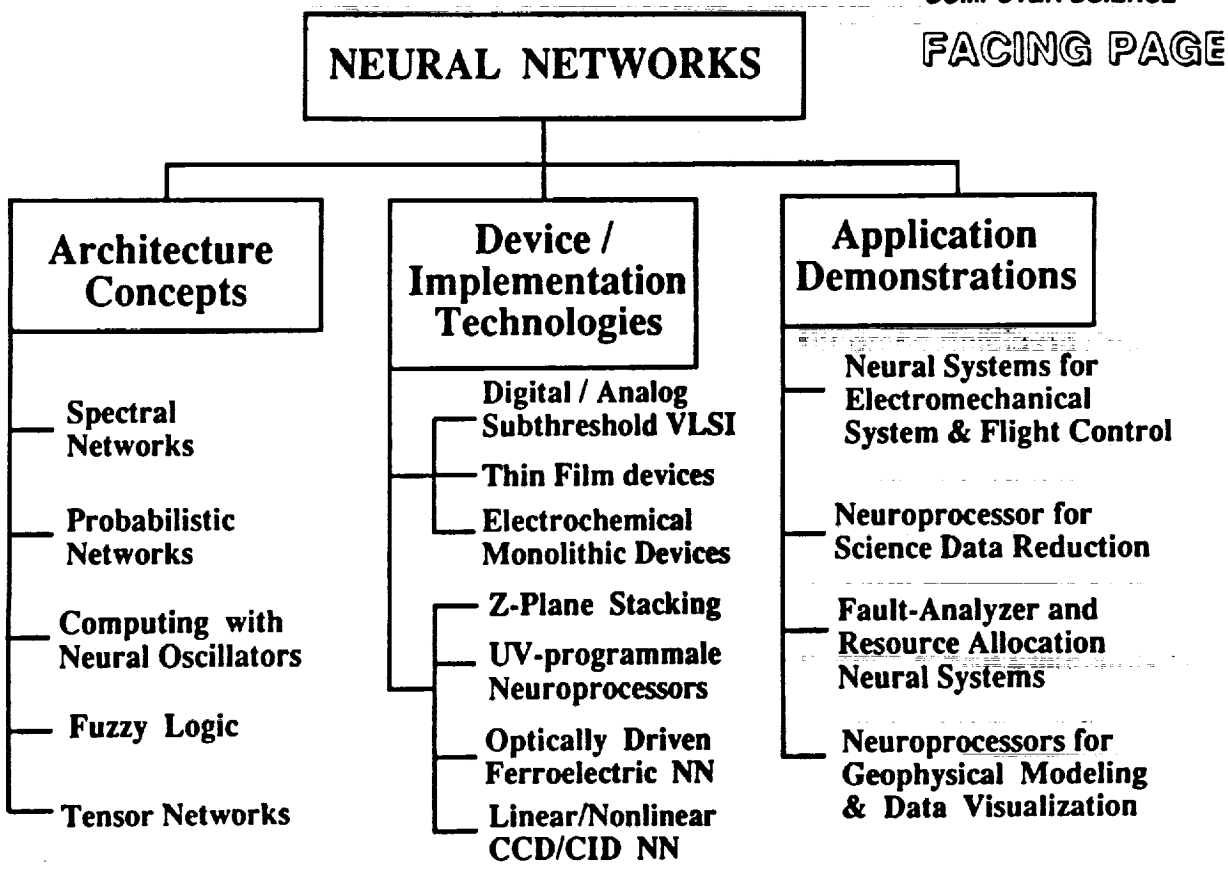

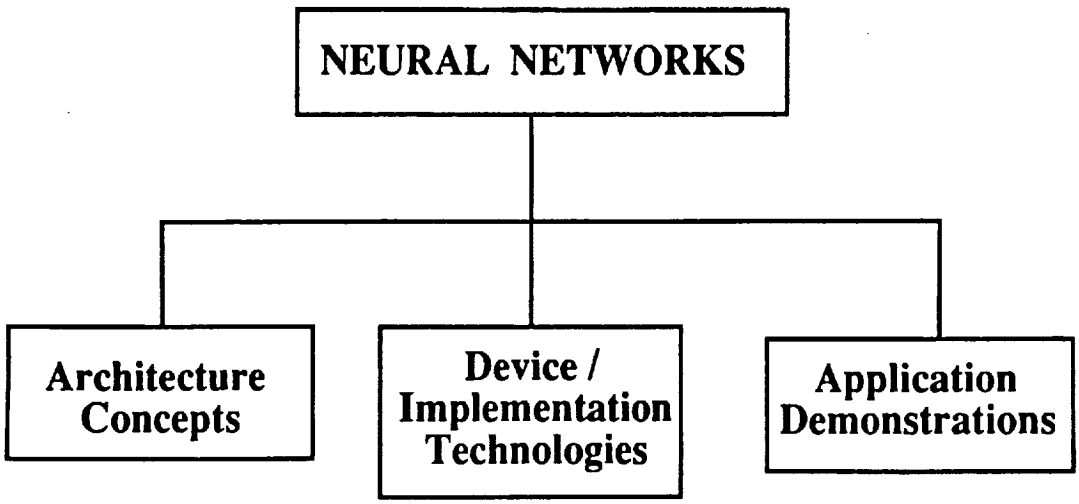

NEURAL NETWORKS BASE R&T
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DATA SYSTEMS & COMPUTER SCIENCE

STATE-OF-THE-ART ASSESSMENT

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ARCHITECTURE CONCEPTS

- extensive research in small size feedforward networks
- limited use of nonlinear dynamics for information processing
  - supervised & unsupervised spatio-temporal learning
  - non-lipschitzian dynamics for fast convergence and unconditional stability
- rudimentary attempts at integrating NN & Fuzzy Logic, NN & Genetic Algorithm
- increasing body of work (US&European) on coupled self organizing networks for control and sensor fusion

DEVICES / IMPLEMENTATION TECHNOLOGIES

- programmable, nonvolatile, high-density binary switches using amorphous semiconductors
- electrochemical solid-state analog memories using composite oxides
- fully parallel, high speed, asynchronous digital and analog custom VLSI (capacitor refresh) synaptic (1024 synapses) and neuron (32 neuron) arrays with 1-13 bits precision
- fully parallel, teraops synchronous, 256 neuron, 65536 synapse CCD/CID chips at 10-12 bits precision with electronic loading

STATE-OF-THE-ART ASSESSMENT

ARCHITECTURE CONCEPTS

- mostly, small size feedforward networks
- limited use of nonlinear dynamics

DEVICES / IMPLEMENTATION TECHNOLOGIES

- programmable, high-density binary switches using amorphous semiconductors
- electrochemical solid-state analog memories
- asynchronous digital and analog custom VLSI synaptic (1024 syn) arrays
- synchronous, 256 neuron, CCD/CID neuroprocessors

APPLICATION DEMONSTRATIONS

- proof-of-concept NN application simulations
- library of cascadable custom VLSI neural chips
- Application Specific Neuroprocessors (ASICs)

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NEURAL NETWORKS BASE R&T
DATA SYSTEMS & COMPUTER SCIENCE

STATE-OF-THE-ART ASSESSMENT (contd.)

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APPLICATION DEMONSTRATIONS

- **Proof-of-concept NN application simulations**
  - On-board star identification and attitude determination
  - Health monitoring / diagnosis and failure prediction for SS APU
  - Tether Satellite System (TSS) control

- **Library of cascadable custom VLSI block chips for flexible and modular implementations of variety of neural network architectures**
  - LandSat imagary interpretation (cartographic analysis)
  - Robot arm control

- **Application Specific Neuroprocessors (ASICs)**
  - Terrain trafficability determination
  - 32 channel target-to-weapons pairing
  - Path Planning for tactical movement analysis
  - Multispectral classification
  - Combustion plume spectral analysis

NEURAL NETWORKS BASE R&T

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CURRENT PROGRAM

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- Identify and develop technologies that could provide revolutionary capabilites for autonomous, adaptive performance

  - Erasable PROM Based on Neural Networks

    - Develop reversible, nonvolatile, high-density, synaptic array that will lead to an associative, fault-tolerant, erasable programmable ROM and explore the potential of such electronic neural networks to NASA's interests. Demo neuroprocessors for:
      (a) dynamic assignment of resources
      (b) supervised learning in analog hardware

    - Theory and applications of massively parallel architecture - Sparse Distributed Memory (SDM)

      - Complete evaluation of Sparse Distributed Memory for automatic recognition of EOS data

NEURAL NETWORKS BASE R&T

DSCS — DATA SYSTEMS & COMPUTER SCIENCE

CURRENT PROGRAM

JPL

- High density, non-volatile, EEPROM based on neural networks

  - Demo neuroprocessors for:

    (a) dynamic assignment of resources
    (b) supervised learning in analog hardware

AMES

- Theory and applications of massively parallel architecture - Sparse Distributed Memory (SDM)

  - Evaluation of Sparse Distributed Memory for automatic recognition of EOS data

NEURAL NETWORKS BASE R&T PROGRAM DESCRIPTION

DSCS — DATA SYSTEMS & COMPUTER SCIENCE

3. APPLICATION DEMONSTRATIONS

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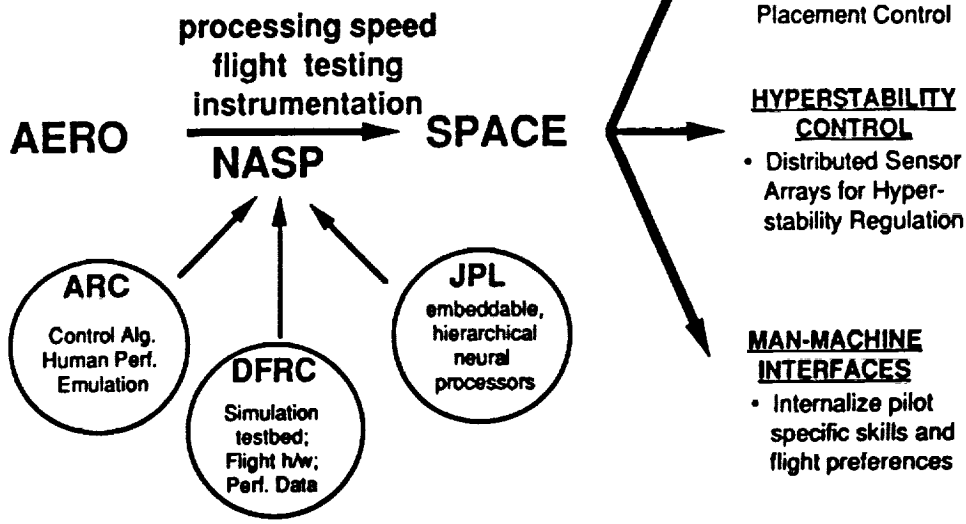
A. Neural System for Electromechanical System and Flight Control

- demonstrate improved control precision during neural control of hypersonic aircraft / spacecraft
  - augment pilot / astronaut skills
  - enhance safety



NEURAL NETWORKS BASE R&T PROGRAM DESCRIPTION

DSCS — DATA SYSTEMS & COMPUTER SCIENCE

3. APPLICATION DEMONSTRATIONS

A. Neural System for Electromechanical System and Flight Control

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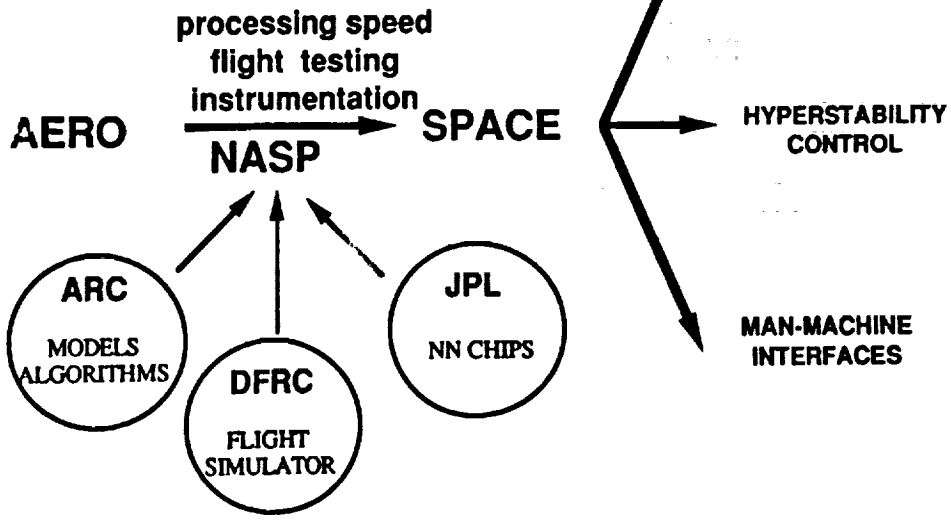

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B. CCD/CID Neuroprocessor for Science Data Reduction

APPROACH

- **Image Compression Phase**
  - extract from image data fundamental invariants (e.g., Lyapunov spectrum, etc.), of hypothesized hiddent dynamics
  - determine dimension of embedding space
- **Image Reconstruction Phase**
  - formulate parameterized map, which when evaluated along an orbit in the embedding space, recovers the original image given as an appropriate initial condition
- **Global Optimization**
  - minimize image distortion and loss of information content, by minimizing a cost function that contains the information on the fundamental invariants of the dynamics

NEURAL NETWORKS BASE R&T
PROGRAM DESCRIPTION
DSCS
DATA SYSTEMS & COMPUTER SCIENCE
3. APPLICATION DEMONSTRATIONS

B. CCD/CID Neuroprocessor for Science Data Reduction

- **Demonstrate 100X - 1000X speedup for onboard data reduction over VLSI AIP brassboard implementing SOA (e.g., Rice's DCT source / channel coding) compression algorithm on CCD/CID neural processor**

- **Develop and demonstrate dynamical systems approach for "lossy" (< 10% RMS) encoding spectral images with > 1000:1 compression ratio**

APPROACH

- construct time series from each image frame
- assume that (possibly chaotic) time series is generated by an unknown dynamical system

  - **Image compression phase** (find invariants of dynamical system)
  - **Image reconstruction phase** (parameterized interative mappings)
  - **Global optimization** (minimize image distortion and loss of info. content)

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C. NEURAL SYSTEMS FOR GEOPHYSICAL MODELING & DATA ANALYSIS

OBJECTIVE
- **model physical phenomena described by PDEs**
- **multidimensional ground-based, processing of space-derived data (e.g., HIRIS, HMMR, SAR) in view of multidisciplinary science analysis**
  - automated cataloging and characterization
  - novelty match filters for recognition of special events

APPROACH
- **breakthrough concept of "spectral" network combines**
  - novel, spatially organized neural architecture
  - spectral formalisms for numerical solution of PDEs

ISSUES
- greater precision using low-precision (<16bit) computing elements
- large scale synchronous, neural chips with upto 1024 neurons/chip
- additional devices/circuits to enable easy implementation of various nonlinearities appearing in PDEs of interest

NEURAL NETWORKS BASE R&T
PROGRAM DESCRIPTION
DSCS
DATA SYSTEMS & COMPUTER SCIENCE
3. APPLICATION DEMONSTRATIONS

C. NEURAL SYSTEMS FOR GEOPHYSICAL MODELING & DATA ANALYSIS

OBJECTIVE
- **model complex physical phenomena (e.g., weather) described by PDEs**
- **multidimensional processing of space-derived data**

APPROACH
- **breakthrough concept of "spectral" network combines**
  - novel, spatially organized neural architecture
  - spectral formalisms for numerical solution of PDEs

ISSUES
- **precision**
- **large-scale synchronous, neuroprocessors**
- **additional devices/circuits for implementation of various nonlinearities**

3. APPLICATION DEMONSTRATIONS

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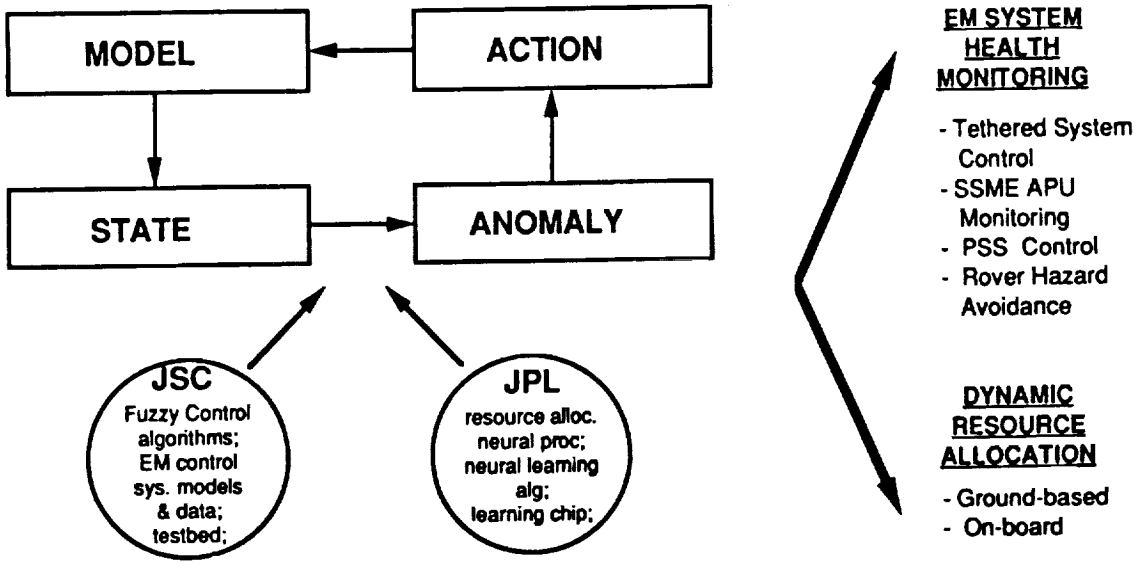
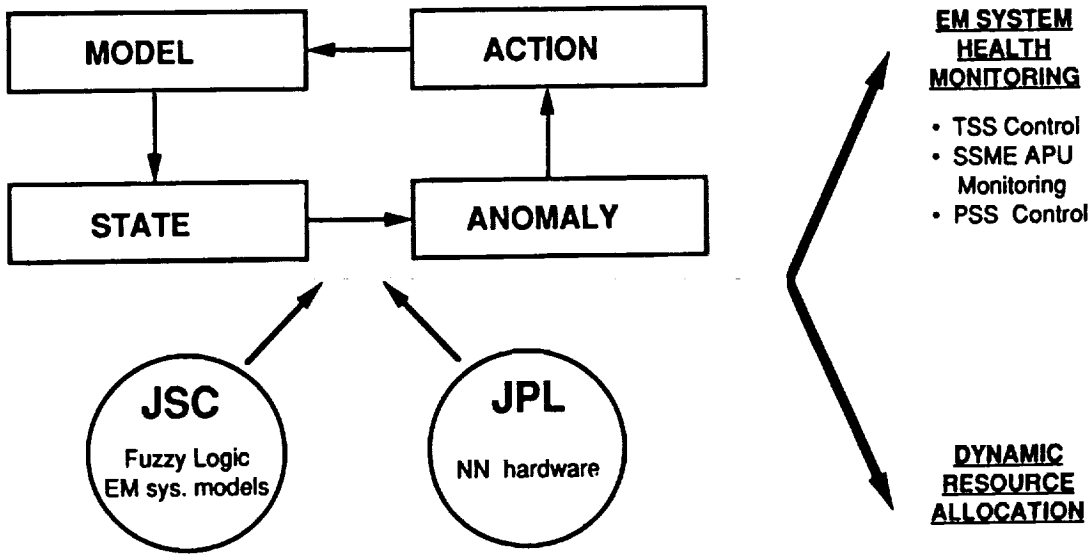
D. FAULT-ANALYZER AND RESOURCE ALLOCATION PROCESSOR

- demonstrate hybrid neural network / fuzzy logic processing architectures for monitoring non-linear complex plants
- demonstrate 64/128 channel analog CMOS VLSI processor for on-the-fly resource allocation



NEURAL NETWORKS BASE R&T PROGRAM DESCRIPTION
DSCS
DATA SYSTEMS & COMPUTER SCIENCE
3. APPLICATION DEMONSTRATIONS
D. FAULT-ANALYZER AND RESOURCE ALLOCATION PROCESSOR

- hybrid NN / fuzzy logic architectures for monitoring complex plants
- 64/128 channel analog neuroprocessor for on-the-fly resource allocation



NEURAL NETWORKS BASE R&T

DSCS — DATA SYSTEMS & COMPUTER SCIENCE

MILESTONES

FY '94 — Baseline CCD/CID spectral neuroprocessor brassboard
- hyperspectral transform on spectral space data (e.g. SAR, HIRIS) at 10 GIPS
- solving nonlinear PDEs at neurochip precision (10-12 bits)

FY '95 — Baseline neuroprocessor for 100X-1000X faster
- onboard, science data reduction
- neural modeling of planetary geophysics / aerodynamic phenomena

FY '96 — Neural system for guidance and landing using thruster / velocity control for
- hypersonic aircraft, e.g., NASP
- planetary landers, e.g., Mars Lander

FY '97 — Hybrid NN / fuzzy logic systems for Tethered Satellite System (TSS) control

Reconfigurable, neuroprocessor for on-board, resource allocation & EM system health monitoring (e.g., SSME APU, PSS)

NEURAL NETWORKS BASE R&T

DSCS — DATA SYSTEMS & COMPUTER SCIENCE

RELATIONSHIP TO EXTERNAL PROGRAMS

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NASA OSF	Health Maintenance / diagnostic and failure prediction for SSME; Hybrid NN / fuzzy logic models; RMS control
NASA OSSA	Tools for multidisciplinary science analysis; spectral classification of space-derived data at high rates; Global geochemical modeling
DOD	Demonstrate performance potential of NN against benchmarked applications, e.g, ATR, continuous speech recognition, sonar signal discrimination, resource allocation, tactical movement analysis
DOE	Theory; applications, e.g., robotics, adaptive process control, stereogrammetry
NSF, NIH, NIMH	Wet neuroscience (elucidation of brain / biological functions); engineering models of bio-functions; theory; algorithms and device technology; prosthetic devices

RELATIONSHIP TO EXTERNAL PROGRAMS

NASA OSF	System health monitoring and failure prediction
NASA OSSA	Multidisciplinary science analysis tools; spectral classification
DOD	ASICs, applications e.g, ATR, signal processing, resource allocation, tactical movement analysis
DOE	Theory; applications, e.g., robotics, adaptive process control, stereogrammetry
NSF, NIH, NIMH	Neuroscience; bioengineering; theory; algorithms and device technology; prosthetic devices

BACKUP CHARTS

NEURAL NETWORKS BASE R&T

NEURAL NETWORKS : Information processing systems that autonomously develop operational capabilities in adaptive response to a dynamically changing environment

- alternative to "programmed" computing, i.e., a "pattern" computer
- emergent "collective" computation
- based on mathematical phenomenology of nonlinear dynamical systems

UNIQUENESS

- massively parallel, distributed and typically asynchronous
- exploit device physics for computation
- inherently fault-tolerant, adaptive

NEURAL NETWORKS BASE R&T

CURRENT PROGRAM ACCOMPLISHMENTS

ARCHITECTURE CONCEPTS

- Large scale SDM demonstrations

DEVICE / IMPLEMENTATION TECHNOLOGIES

- Programmable, high density binary switches using amorphous semiconductors
- Library of cascadable custom analog VLSI building block chips

APPLICATION DEMONSTRATIONS

- Neural star tracker
- Robot arm control
- Dynamic resource allocation

CURRENT PROGRAM ACCOMPLISHMENTS

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ARCHITECTURE CONCEPTS

- **Large scale SDM demonstrations**
  - 2-D shape recognition
  - weather prediction simulation on the Connection Machine
  - discrete speech recognition

DEVICE / IMPLEMENTATION TECHNOLOGIES

- **Programmable, high density (> 10^7 synapse/cm^2) binary switches using amorphous semiconductors**
- **Library of cascadable custom analog VLSI building block chips**
  - 32 neuron, 1024 synapse, 1-13 bit precision, capacitor refresh chip
  - 64 neuron (variable gain) chip
  - 32 channel, programmable, dynamic assignment chip

APPLICATION DEMONSTRATIONS

- **Neural star tracker for attitude determination and precision recovery**
- **Robot arm control**
- **Dynamic resource allocation**

NEURAL NETWORKS BASE R&T
DSCS DATA SYSTEMS & COMPUTER SCIENCE

NEURAL SYSTEM FOR ELECTROMECHANICAL SYSTEM AND FLIGHT CONTROL

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- **PROPULSION ONLY FLIGHT CONTROLLERS**

  - Hybrid controllers that augment propulsion only backup control system during landing or maneuver in the event of system failure, to emulate a conventional menu of flight controls (flair, dutch roll, turbulence, etc.) using standard linear and neural control methods

- **SHOCK WAVE PLACEMENT CONTROL FOR HYPERSONIC VEHICLES**

  - Speed, altitude and attitude determine shock wave position. Improper position can lead to stagnant heat dissipation areas which can burn through vehicle structure and impact air flow to the engine

  - Develop controllers using slow time-scale simulations (X-15 / shuttle data) for predicting shock wave placement. Neural Networks behavior would be evaluated against pilot behavior recorded during shock wave guidance maneuvers

  - NASP technology requirements

NEURAL NETWORKS BASE R&T

DSCS — DATA SYSTEMS & COMPUTER SCIENCE

NEURAL SYSTEM FOR ELECTROMECHANICAL SYSTEM AND FLIGHT CONTROL

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- **DISTRIBUTED SENSOR ARRAYS FOR HYPERSTABILITY REGULATION**
  - **Sensor fusion and interpretations required for aircraft stability during**
    - abnormal flight modalities (e.g., wind shear)
    - high agility aircraft maneuvers (e.g., ATF]

    Difficult for human pilot because of information overload and response speed requirements
  - Design controllers capable of using distributed information arrays to develop representations of critical aerodynamic and atmospheric phenomena (e.g., wing vortices or microburst) impacting flight control
- **HUMAN-MASTER / NEURAL NETWORK PUPIL FLIGHT CONTROL ARCH.**
  - **Develop trainable controllers which under pilot supervision would internalize pilot specific skills and flight preferences, thereby augmenting pilot performance during**
    - unusual task tradeoffs
    - short response times
    - emergency situations

NEURAL NETWORKS BASE R&T PROGRAM DESCRIPTION

DSCS — DATA SYSTEMS & COMPUTER SCIENCE

1. ADAPTIVE CONCEPTS

TECHNOLOGY ELEMENT	ATTRIBUTE	SOA	TARGET
SPECTRAL NETWORKS	• spectral sol. of PDEs	1-D linear PDEs	3-D nonlinear PDEs
	• spectral transforms precision issues	1-D transforms unaddressed	n-D transforms to be addressed
INTERPOLATING POLYNOMIAL NETWORKS	prob. density finder in multidimensional parameter space;	2-D density maps assumed shape of underlying prob. fn. (e.g., normal)	n-D density map arbitrary dist.
• HONN			
• PNN			
• INFOLDING NETS	tuning n/w parameters	manual	automatic
• TENSOR NETWORKS	problem DOF	low (< 5)	high (> 10)
HYBRID FUZZY LOGIC / NEURAL NETWORK MODELS	framework to embed heuristics & exp. knowledge with numeric computing	simple, linearized dynamical sys.	complex non-linear dynamical systems
		limited DOF nonadaptive	large DOF adaptive

NEURAL NETWORKS BASE R&T PROGRAM DESCRIPTION

2. DEVICE / IMPLEMENTATION TECHNOLOGIES (CONTD.)

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TECHNOLOGY ELEMENT	ATTRIBUTE	SOA	TARGET
Z-PLANE STACKING TECHNOLOGY	compact 3-D integration	32 chip stack	256 chip stack
		1K sensor array	64K array
	Increase in n/w size and capability ;	mem.-processor preprocessing	sensor-proc. preprocessing
CHARGE DOMAIN COMPUTING DEVICES (CCD/CID)	massively parallel	256 Neuron	1024 Neuron
		65K synapses	10^6 synapses
	ultra-fast reconfigurable	1ms	10ns
	high precision	8-10 bits	14-16 bits
	addressability	electronic	elec./optical
	ultra-low noise		
	synchronous		
UV-PROGRAMMABLE ADAPTIVE DEVICES (ON-CHIP LEARNING)	network dimensions	1K synapses	64K synapses
	precision	9 bits	12 bits
	retentivity	~ months	~ years

NEURAL NETWORKS BASE R&T PROGRAM DESCRIPTION

DSCS — DATA SYSTEMS & COMPUTER SCIENCE

2. DEVICE / IMPLEMENTATION TECHNOLOGIES

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TECHNOLOGY ELEMENT	ATTRIBUTE	SOA	TARGET
ELECTROCHEMICAL SOLID-STATE SWITCHING TECH.	fabrication status	single device	1K syn. array
	precision	8 bits	11 bits
	inherently noise immune	SEU immune	SEU immune
	inherently rad-hard	β-radiation	α, γ-radiation
	nonvolatile	months	years
AMORPHOUS SEMICONDUCTORS	ultra-high density	$10^7/cm^2$	$10^9/cm^2$
	2-terminal configuration	binary	analog
	rad-hard	β-radiation	α, γ-radiation
FERROELECTRIC CMOS VLSI TECH.	fabrication status	single device	1K syn. array
	high speed	100ns	10ns
	optically addressable	device level	array level
	rad-hard	DOD milspec	mission specific
OPTOELECTRONIC INTERCONNECTION TECH.	ultra-high speed	10^8 connect/sec	10^{14} connect/sec
- high speed optical correlators	massive connectivity	10^6 interconnect.	10^8 interconnect.
- thermoplastic holograms	integration status	optical bench	OEIC
- tertiary filters			

NEURAL NETWORKS BASE R&T PROGRAM DESCRIPTION

2. DEVICE / IMPLEMENTATION TECHNOLOGIES

TECHNOLOGY ELEMENT	ATTRIBUTE	SOA	TARGET
OPTICALLY ADDRESSABLE FERROELECTRIC THIN FILM DEVICES	fabrication status high speed optically addressable rad-hard	single device 100ns device level DOD milspec	1K syn. array 10ns array level mission specific
Z-PLANE STACKING TECHNOLOGY	compact 3-D integration increase in n/w size and capability ;	32 chip stack 1K sensor array mem.-processor preprocessing	256 chip stack 64K array sensor-proc. preprocessing
CHARGE DOMAIN COMPUTING DEVICES (CCD/CID)	massively parallel ultra-fast reconfigurable high precision addressability ultra-low noise synchronous	256 Neuron 65K synapses 1ms 8-10 bits electronic	1024 Neuron 10^6 synapses 10ns 14-16 bits elec./optical
UV-PROGRAMMABLE ADAPTIVE DEVICES (ON-CHIP LEARNING)	network dimensions precision retentivity	1K synapses 9 bits ~ months	64K synapses 12 bits ~ years

NEURAL NETWORKS BASE R&T

Element Characterization Table

PROGRAM ELEMENTS

Products	prob. density finder in multidimensional parameter space; bos parameter space	Fourier, Hartley, Discrete Cosine transforms; Data Compression	robust and fast classifier; combinatorial opt.	spectral solution of PDEs (e.g., weather); spatial self-organization (spatio-temporal correlation);
Electronic / Opto-Electronic Implementation Technologies	direct interfacing to large sensor arrays; [illegible] modular increase in n/w size & separability; [illegible] compact packaging	full connectivity; low noise; synchronous operation; rad-hardened;	asynchornous operation; high speed; high precision; power stringent;	large dynamic range; optical loading; noise immune; ultra-high density ; compact packaging; high cyclability; rad-hardened
Novel Computing Technologies	high precision; compact cell design; fast programmability; nonvolatile; low noise;	massively parallel teraops performance; ultra-fast programmability;	high speed; direct interface to sensors; non volatile; ease of progammability;	massively parallel teraops performance (CID); arbitrary precision; non-volatile;
	Neural Processor for Electromechanical System and Flight Control	**CCD/CID Neuroprocessor for Science Data Reduction**	**Fault-Analyzer and Resource Allocation Processor**	**Neural Systems for Geophysical Modeling & Data Visualization**

END-USER PRODUCTS

NEURAL NETWORKS BASE R&T

DSCS — DATA SYSTEMS & COMPUTER SCIENCE

Element Interaction Summary Table

PROGRAM ELEMENTS					ENABLING / ENHANCING FEATURES
Architecture Concepts	Infolding Neural Networks Fuzzy Logic	Spectral Transforms Chaotic Dynamics	Hybrid NN / Fuzzy Logic Models Global Optimization	Spectral Neural Networks Spatio-Temporal Pattern Processing	• 2 to 4 orders of magnitude faster • fault-tolerant
Electronic / Opto-Electronic Implementation Technologies	Z-plane stacking technology	256-Neuron synchronous analog CCD/CID Processor with digital interface	64 / 128 channel Analog VLSI chip	1024-Neuron CCD/CID chip; Electrochemical monolithic analog elements 2-terminal thin film analog synapses;	• ultra-fast dynamically reconfigurable • real-time adaptation
Novel Computing Technologies	UV-programmability for On-chip adaptation	Linear CCD/CID technology	Optically driven ferroelectric NN	Nonlinear CCD/CID technology Amorphous semiconductor nonlinear devices	• power, size & weight stringent • space qualifiable / rad. resistant • low noise
	Neural Processor for Electromechanical System and Flight Control	CCD/CID Neuroprocessor for Science Data Reduction	Fault-Analyzer and Resource Allocation Processor	Neural Systems for Geophysical Modeling & Data Visualization	

END-USER PRODUCTS

NEURAL NETWORKS BASE R&T

DSCS — DATA SYSTEMS & COMPUTER SCIENCE

SOA ASSESSMENT

International Perspective

- Human Frontier Science Project (Japan, France, Canada, USA)
  - elucidation of brain functions, e.g., perception, cognition, memory
  - elucidation of biological functions, e.g., expression of genetic information
- Bio-electronic Devices (MITI)
  - engineering models of bio-functions
- European Strategic Program for R&D in Information Technology (France, UK, Spain, Germany, Portuga)
  - *PYGMALION* - neural networks for image and speech processing
  - *ANNIE* - neural network software technology: robotics, acoustic data processing
  - *BRAIN* - basic research in adaptive intelligence and neurocomputing
- DARPA's Neural Network Initiative
  - demonstrate performance potential of neural networks against benchmarked applications : ATR, continuous speech recognition, sonar signal discrimination, seismic signal discrimination

International Perspective
Some Illustrative Funding Profiles

• **France (ESPRIT) :**	
PYGMALION	**$6M over 2 years**
ANNIE	**$6M over 3 years**
• **BRAIN (EC) :**	**$4.8 M over 2 years**
• **Germany**	
Information Processing in Neural Arch, :	**$18 M for Fy '91-93**
• **Japan (STA) :**	
Riken Frontier Science Program	**$45M for 15 years**
Biodevice Program	**$25M for 10 years**
Brain Functions Program	**$1.5M for 3 years**
• **Japan (MITI)**	
Human Frontier Science Program :	**$42M for FY '90-91**
Sixth Generation Computing Program	**$30M a year**
• **DARPA's Neural Networks Initiative**	**$33M for 28 months**

NEURAL NETWORKS BASE R&T
DSCS DATA SYSTEMS & COMPUTER SCIENCE

RATIONALE FOR NASA INVESTMENT

- **Demonstrated the potential to impact a number of focused NASA programs, at a fraction of cost of conventional supercomputers**
  - Early large payoff base for existing scientific problems in geophysics, science and control independent of future mission requirements
- **NASA's requirements far exceed those of other federal agencies for near- to mid-term scenarios**
  - computational performance : unmatched data rate and volume
  - ultra-high density/ ultra-compact / ultra-light devices (except SDIO, Air Force)
  - rad-hard neuroprocessors (except SDIO)
  - power stringency
  - long term life
- **Reduced dependence on DOD investment strategy / profile**

NEURAL NETWORKS BASE R&T

INTERCENTER ROLES

JPL (LEAD CENTER)
Design and fabricate Analog VLSI and CCD/CID based neural processors; high-density nonvolatile memories; advanced neural learning and optimization algorithms; spectral algorithms

ARC
Flight and spacecraft controllers for data analysis; Advanced learning algorithms for Neural control; Novelty Match Filters; SDM architectures coupling Genetic Algorithms and Neural Networks

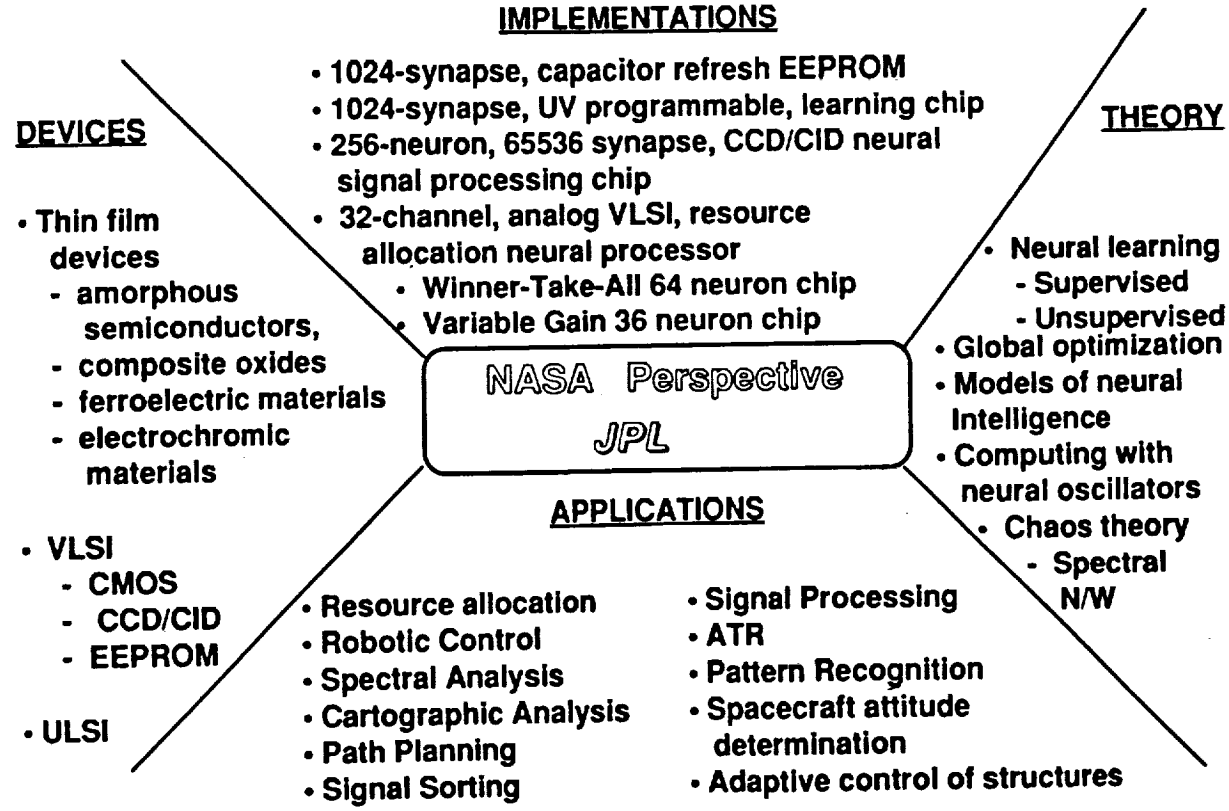
JSC
Advanced Neural Network algorithm design tools; architectures coupling Fuzzy Logic, Neural Network Models and Genetic Algorithms

GSFC
Neural Network architectures for data-management / characterization

LaRC, MSFC, LeRC
Application domain expertise : robotics, space structures control, autodocking & rendezvous, etc.

NEURAL NETWORKS BASE R&T

DSCS — DATA SYSTEMS & COMPUTER SCIENCE



NEURAL NETWORKS BASE R&T

DSCS — DATA SYSTEMS & COMPUTER SCIENCE

BIOCOMPUTATION

- Mathematical & physiological understanding of biological systems and control mechanisms
  - vestibular macala
  - Reverse engineering, visualization and quantitative morphological modeling tool development
  - Human performance studies
  - Functional analysis
  - zero-g physiology

SPARSE DISTRIBUTED MEMORY

- Biological info. processing
- Digital prototype
- Connection Machine simulation
- Applications to
  - speech recognition
  - weather prediction
  - large scale CAM databases
  - motor control
  - 2-D shape recognition
  - Landsat image analysis

THEORY

- Tensor Networks
- Probabilistic Neural Networks
- Hybrid architectures
  - SDM & GA
- Higher Order Neural Networks (HONNs)
- Adaptive neurocontrol algorithms
- Novelty match filters
- Time series prediction

NASA Perspective

ARC

APPLICATIONS

- Autodocking & Rendezvous
- Planetary lander control
- Aricraft landing control
- Thruster / velocity control
- Sensorimotor coordiantion
- Life support system control
- Robot control
- Path Planning
- Balance control
- Geophysical data characterization
- Human performance monitoring & simulation

NEURAL NETWORKS BASE R&T

DSCS — DATA SYSTEMS & COMPUTER SCIENCE

GSFC

- multidisciplinary processing of spatio-temporal space-derived data
  - automated cataloging & characterization
  - embedding domain context
  - detection of subtle correlations among large no. of variables
  - novelty match filters

LaRC

- Aircraft / spacecraft landing control
- Control of rigid / flexible structures
- Robot motion planning
- Aircraft stabilization during flight

MSFC

- Control of flexible structures
- Autodocking & Rendezvous
- Shuttle arm control
- Pattern recognition
- Robot control

NASA Perspective

LeRC

- Multidisciplinary aerodynamic, aerothermodynamic simulation and design optimization
  - spacecraft / propulsion control sytem design
  - science instrument / antenna design
- EM control system health monitoring, e.g., Chem Transfer Engine (PATHFINDER)

NASA INFORMATION SCIENCES & HUMAN FACTORS PROGRAM

ANNUAL REPORT, 1990

June 26, 1991

Office of Aeronautics, Exploration and Technology
National Aeronautics and Space Administration

Data Systems

The Data Systems Program consists of research and technology devoted to controlling, processing, storing, manipulating, and analyzing space-derived data. The objectives of the program are to provide the technology advancements needed to enable affordable utilization of space-derived data, to increase substantially the capability for future missions of on-board processing and recording and to provide high-speed, high-volume computational systems that are anticipated for missions such as the evolutionary Space Station and Earth Observing System.

The Data Systems Program supports fundamental research in such areas as laser diodes, supports work to select and provide the appropriate on-board processor technology for future NASA missions, and also supports the development of two flight processors with special architectures. The ongoing support for solid-state laser research leads directly to the development of a nine laser diode array that is used in the Optical Disk Recorder. Some laser research efforts are focusing on Space Station data handling applications. These devices are being developed to handle both the 300 Mbit/sec basic data rate and the much higher rates needed to support networking and computer internal communications. Complementary research is being supported to characterize the fundamental performance and properties of various alternative networking.

NASA missions require processors that will work very reliably in the space environment. Computer systems for missions in polar orbit and some planetary missions must operate reliably in high radiation environments. The Data Systems Program capitalizes on the dramatic advances in electronics, computer systems, and software that are occurring in both the public and private sectors. It fosters and leads the development of technologies required to meet NASA's unique data systems needs. NASA technical expertise is being applied in cooperative arrangements with DoD, and products from the DoD VHSIC program and other DoD developments are being assembled into processors for testing and evaluation.

The Advanced Digital Synthetic Aperture Radar (SAR) Processor includes a special architecture and algorithms to process SAR data. The unit will have a compute rate of 6000 megaflops per second. The Massively Parallel Processor (MPP) is being used for ground processing of space image data, SAR data, and spectral analysis. The MPP utilizes 16,384 processors. The research applications developed on the MPP have verified the expected tremendous computational power of the MPP for the target applications. Researchers outside of NASA in several universities, research centers, and industry have been given access to the MPP to gain an understanding of its capabilities, and they have applied these unique resources to a broad range of computational problems.

Future objectives through the Civil Space Technology Initiative in High Rate/High Capacity Data include data system architectural studies for new space initiatives, significant advances in technologies and capabilities for on-board image processing, data compression, high-volume block access storage, data networks, spectrometry, and adaptive sensor control.

Program Manager: Paul Smith
NASA/OAET/RC
Washington, DC 20546
202/453-2753

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Algorithms/Applications – FY90 Configurable High-Rate Processor System (CHRPS)

The focus of this program is to develop and demonstrate algorithms and applications that can exploit, in Earth orbit, the high-capacity processing capabilities provided by Configurable High Rate Processor System (CHRPS). These algorithms are generally categorized as data compression and data analysis. We plan to demonstrate that the CHRPS concept will allow scientists, from their laboratory, to program and control on-board high-rate processing and receive only the meaningful results at their workstations.

In FY 1990, this task developed a lossless data compression package that provides a selection of compression algorithms from which a user can choose the one most appropriate to the data set at hand. This package was presented to the National Space Science Data Center (NSSDC) User Group and installed on the NSSDC VAXCluster for experimental use by that user community.

In addition, a multispectral image compression scheme was developed based on region growing and quadtree data structures that compress multispectral images to three different levels: browse, moderate loss, and lossless. Browse resolution results of this scheme are shown on the accompanying illustration in the righthand column. This scheme achieves a 20:1 compression ratio by locating and retaining only the edges of regions and discarding the texture information held within the regions. New schemes retaining different types of information are targeted for development in FY 1991.

The SPAM (Spectral Analysis Manager) software was installed on the Science Information Systems Center's VAXCluster. Two SPAM analysis approaches, spectral matching and mixture analysis, were selected for FY 1991 use in evaluating the effect of data compression on AVIRIS analyses.

In FY 1991, evaluation of a least three approaches to data compression for AVIRIS data will be performed. Analysis scenarios for use in data compression evaluation of simulated MODIS data will be selected. Three additional algorithms will be added to the baseline (NSSDC) compression package. Evaluation will be performed of at least three approaches to data compression for MODIS data. A report will be prepared comparing results using the baseline (NSSDC) compression package for a wide variety of data set types.

Technical Contact
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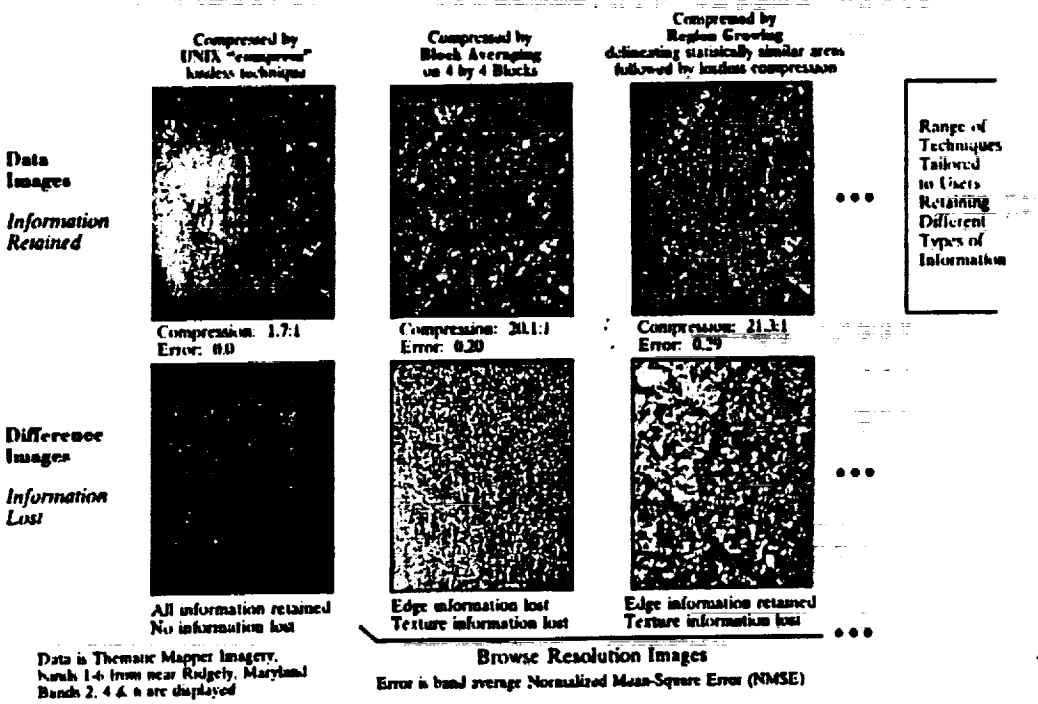
Lossless Data Compression



Automatic Image Data Encoding and Analysis

Our main objective is to perform fundamental research in automated approaches for encoding multispectral imagery data into image segments based on the spatial structure of the multispectral data and to investigate automated methods for analyzing this encoded data on a segment-by-segment basis. A secondary objective is to develop criterion for evaluating the effectiveness of our analysis approaches on NASA remotely sensed image data.

There are a variety of ways for determining ground reference data for satellite remote sensing data. One of the ways is to photo-interpret low altitude aerial photographs and then digitize the cover types on a digitizing tablet. The resulting ground reference data can then be registered to the satellite image, or, alternatively, the satellite image can be registered to the ground reference data. Unfortunately, there are many opportunities for error when using a digitizing tablet and the resolution of the edges for the ground reference data depends on the spacing of the points selected on the digitizing tablet. One of the consequences of this is that when overlaid on the image, errors and missed detail in the ground reference data become evident. This task developed an approach for correcting these errors and adding detail to the ground reference data through the use of a highly interactive, visually oriented process. This process involves the use of overlaid visual displays of the satellite image data, the ground reference data, and a segmentation of the satellite image data.

Several programs were implemented on the Science Information Systems Center (SISC) VAXCluster and with an IVAS image display system to effect interactive editing of an edge map from an image segmentation so as to leave only those edges that correspond to boundaries between the ground cover types distinguished by the ground reference file. The resulting refined ground reference file then can be used for more accurate evaluation of new image analysis algorithms.

At the point funding ran out for this task, the interactive line editing programs have been applied to a 128 x 256 pixel portion of a Landsat Thematic Mapper data set, giving excellent results. When more funds become available, this refinement technique will be applied to several other tests' data sets and ground reference files.

Technical Contact
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Configurable High-Rate Processor System (CHRPS)

The goal of the Configurable High-Rate Processor System (CHRPS) is to provide the architecture, system control, and high-rate data handling interfaces needed to support on-board compression, information extraction, and automated operations of high-rate imaging missions.

The next generation of imaging sensors will provide measurement capability at finer spectral and spatial resolutions, resulting in data rates exceeding the capability of the Tracking and Data Relay Satellite System (TDRSS) and exceeding the capacity of ground-processing systems and analysis teams. Interdisciplinary studies will require coordinated observations and integrated analysis of data from these sensors. The CSTI Data System Program is developing image processing and optical disk recorder technology to support on-board data compression, information extraction, and data buffering for these high-rate missions.

The objective of CHRPS is to apply high-rate network technology and develop the packet telemetry handling interfaces to enable the processing and buffering components to be configured for a range of operations from single instrument data compression to multisensor fusion and feature extraction. The CHRPS development will produce a phased testbed to demonstrate technology components for project applications such as EOS to support the integration of technology into space platform architectures and to support the evaluation of on-board processing functions. Support is building within NASA and the DoD to use the CHRPS testbed as a technology demonstration resource.

During FY 1990, the two contract study teams preparing Phase-B designs for the EOS Data/Information System completed special emphasis studies defining project requirements for high-capacity processing on board the EOS platforms. Generation of high-level data products for direct broadcast to low-cost ground stations emerged from these studies as the prime subject of interest to the EOS Project because EOS may fly direct broadcast on POP-A but with no processing or storage. The EOS Project stated that Code R activity (to develop prototype and demonstrate enhancing technologies in support of the direct broadcast capability) will make significant contributions to the EOS Project, if requested funding levels are approved.

In FY 1991 we will develop and refine scenarios for on-board data product computation in support of the EOS direct broadcast capability. This activity will be performed in collaboration with the EOS Project and will be used as an avenue to achieve continued visibility of the concept within the EOS Project.

Technical Contact
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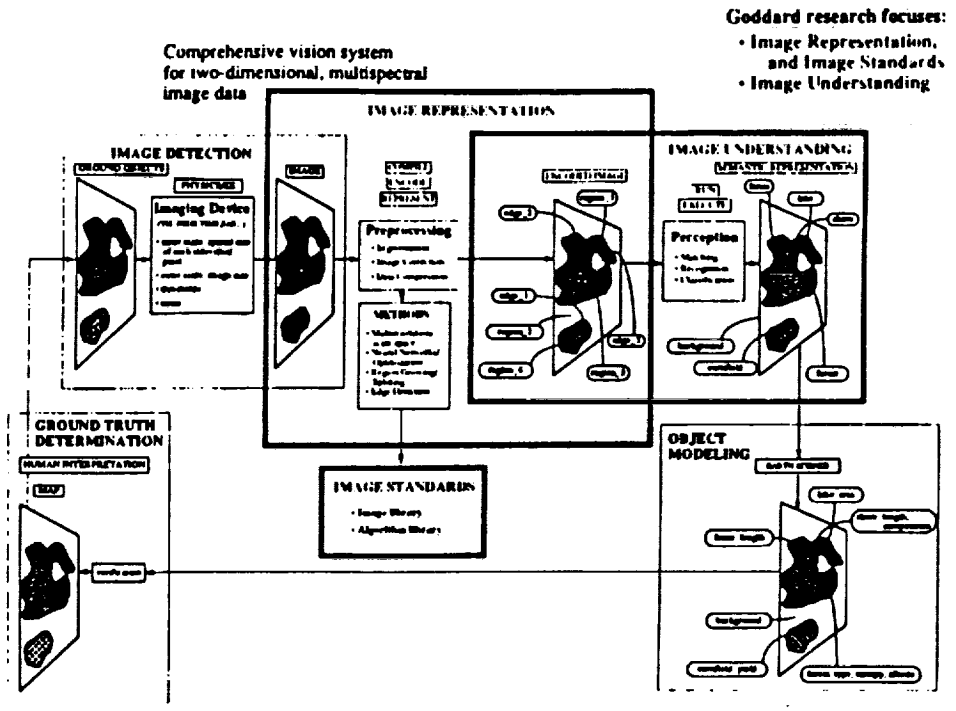
Comprehensive Vision System



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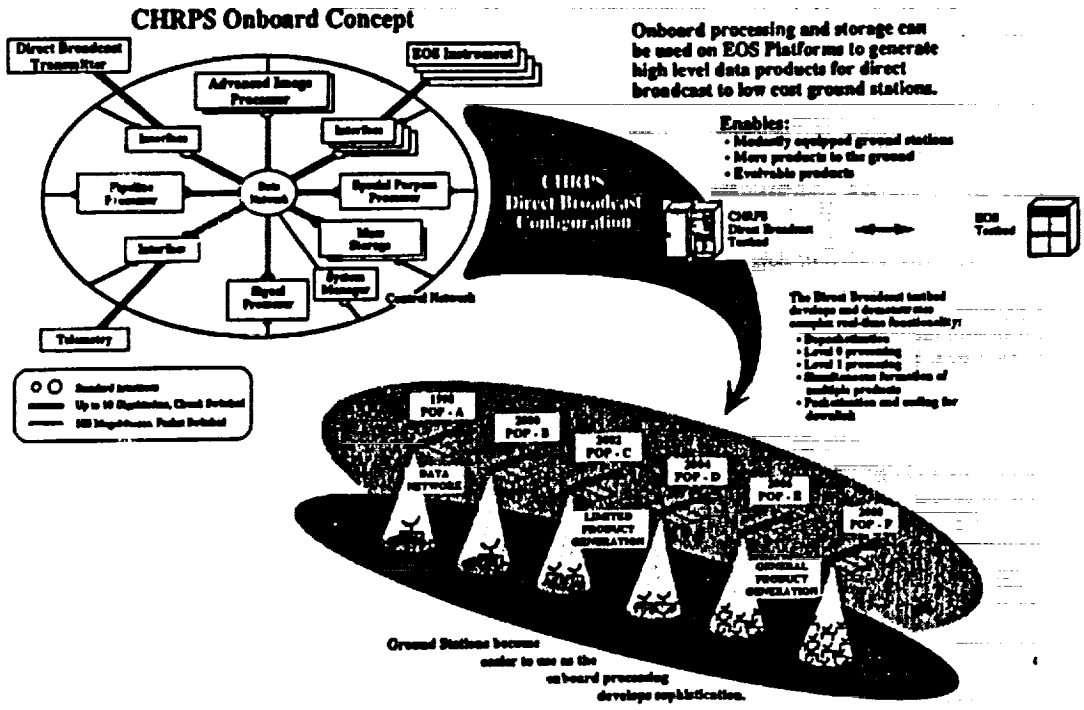
CHRPS Architecture



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Gallium Arsenide (GaAs) Pipeline Processor

The objective of this program is to advance on-board ultrahigh-speed data acquisition and processing of scientific data. The Earth Observatory Spacecraft/Geodynamics Laser Ranging System (EOS/GLRS) scientific requirement is to acquire data in "snapshots" at rates up to 12 billion bits per second and to preprocess data on board prior to transmission to ground using radiation hard, low-power integrated circuit technology. The solution lies in a pipeline processor architecture implemented in high-speed GaAS technology.

NASA and the Office of Naval Research (ONR) initiated a program with Rockwell International for the development of an advanced, Ultrahigh-Speed Data Acquisition (USDA) system. This system will be capable of digitizing an incoming analog signal at 8-bit resolution and a sampling rate of 1.5 giga-samples per second, storing the resulting digital information for a period of 1.4 msec, and upon command, reading out the stored information at a rate compatible with the pipeline data processing hardware. The high-speed data acquisition system addresses an immediate need within NASA for data recording in the GLRS. It also addresses generic requirements within the Navy, particularly in providing the basis for flexible, affordable, light weight, satellite-based electronic systems with advanced capabilities. The ultrahigh-speed electronics technologies developed in this program are key technologies for advanced communication systems, high bandwidth remote sensing and signal processing, and high-rate data processing.

Development of High Electron Mobility Transistor (HEMT) memory circuits has been proceeding at Rockwell under ONR/NASA sponsorship. This effort has led to the demonstration (in FY 1990) of fully functional 1K Random Access Memory (RAM) and 99.8% functional 4K RAMs with ultrahigh-speed (read access time down to 0.6 nsec) and low power (chip power of 0.3 W for 1K RAM), with an access time of 2.0 nsec. Also, in FY 1990 the University of Idaho completed the architecture design of a general purpose pipeline processor which uses a reconfigurable data path processing chain.

Technical Contact
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GaAs Pipeline Processor

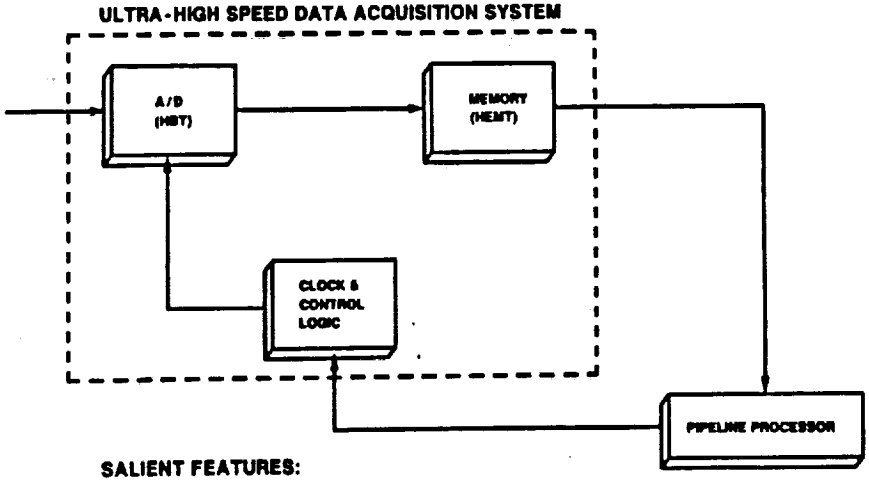
NASA POTENTIAL USERS:

GEODYNAMIC LASER RANGING SYSTEM
DIGITAL AUTO-CORRELATION SPECTROMETER
DSN/DIGITAL RECEIVER

PARTICIPANTS:

OFFICE OF NAVAL RESEARCH
ROCKWELL IRD
NASA

ULTRA-HIGH SPEED DATA ACQUISITION SYSTEM



SALIENT FEATURES:

DIGITIZATION RATE: 1500 MILLION SAMPLES PER SEC. AT 8 BITS PER SAMPLE
STORAGE PERIOD: INCREMENTS OF 1.4 MICRO-SEC.
POWER: LESS THAN 15 WATTS

SIMD CHIP – FY90 Configurable High Rate Processor System (CHRPS)

The objective of this research is to demonstrate the feasibility of a flight-qualifiable compute engine able to sustain at least one gigaflop per second when performing data compression and image analysis algorithms.

Most data compression and image analysis algorithms including synthetic aperture radar signal processing can be readily performed by computers with a very large number of processing elements controlled by a main control unit. This type of computer architecture is generally called the Single-Instruction-stream Multiple-Data-stream (SIMD) architecture. The SIMD architecture is a good match to applications that involve massive numbers of data elements, all being processed in a similar manner. It is inherently more energy efficient than any other parallel computer architecture since only one controller and one program memory are required to control a massive number of processors.

In FY 1990, the Microelectronics Center of North Carolina (MCNC), operating under a second year NASA grant, designed, fabricated, and demonstrated on a test board a fully functional custom CMOS integrated circuit containing 128 processing elements implemented with 1,109,340 transistors. A rad-hard version of this chip is the basic building block of a massively parallel gigaflop compute node.

In FY 1991, we will contract with AT&T Bell Laboratories to define the approach, schedule, and cost to produce a rad-hard version of the MCNC chip.

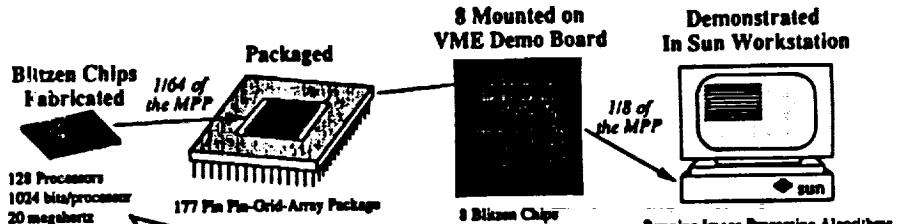
We will explore the establishment of collaborations with several Earth scientists and astrophysicists involving application of a high rate processor to address their upcoming requirements. Candidate areas are prototype Earth Observing System (EOS) instrument testing in aircraft, EOS direct readout data product formation in space, and Hubble Space Telescope (HST) third generation instrument imbedded processing. We will derive requirements and detailed scenarios based on a network architecture or an imbedded processor to express their requirements.

We will initiate design of a scalable prototype system incorporating the MCNC chip component to address the processing and data handling requirements derived from the above mentioned collaborations. Options for packaging such a prototype system include high-density approaches such as the stacked silicon modules being developed by Irvine Sensors, and the thermal conduction unit being developed by MCNC.

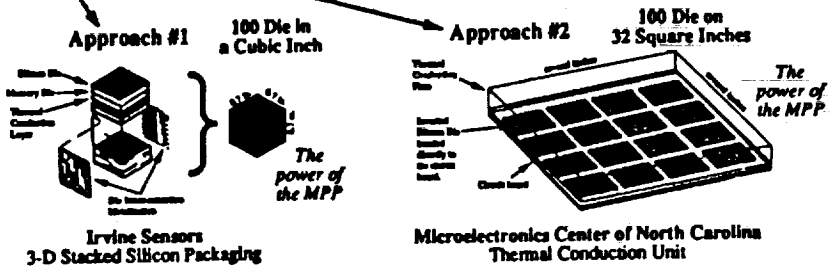
Technical Contact
James Fischer, GSFC, (301) 286-3465

SIMD Chip

FY 89-90 Chip Development



FY 91 High Density Packaging



FY 92 Utilization

Enable accelerated development time tables for prototype EOS instruments

- Collaborate with two Earth scientists developing prototype imaging sensors
- Demonstrate high speed processor systems performing realtime data processing in their aircraft onboard data systems.

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Source Encoding (Lossless Data Compression)

The objective of this program is to develop source encoding technology to maximize information return from science instruments on space platforms by reducing the requirements for on-board storage and/or channel communication bandwidth.

High resolution imaging science instruments in conjunctions with large space platforms are driving the telemetry bandwidth requirements to exceed what is currently available in the NASA Tracking and Data Relay Satellite System (TDRSS). As a result of the TDRSS bandwidth constraints some form of on-board processing is required to reduce the science instrument data rate. In addition, by reducing the science data rate additional information can be stored on the on-board tape recorder prior to playback through the telemetry channel. In the past, lossless data reduction was mostly implemented with the well-known Huffman code, an optimal source coding scheme for known data statistics which determines the code book. The code book assigns shorted code words to source samples occurring more frequently and longer code words to less-frequent samples. From our analysis at GSFC we have established that the Rice coding scheme is a collection of Huffman codes designed at various entropy ranges, without the need to store any code book. The major advantage of Rice's coding scheme is its simple coding structure, which lends itself easily to hardware implementation.

Completed in FY 1990 was a Very Large Scale Integration (VLSI) logic design of a multiuser source coder and decompressor chip set at the University of Idaho. The source coder is adaptive to source statistics and can operate at data rates up to 10M samples per second. Also completed were data compression simulations (based on the VLSI design algorithm) for both imaging and nonimaging science data sets. These simulations included data generated by the following instruments: Michelson Doppler imager/SOHO, NRL and Lockheed instruments on Orbiting Solar Laboratory (OSL), and Lunar Gamma-Ray Spectrometer. Initiated in FY 1990 was a design of a Configurable High-Rate Processor (CHRP) testbed Image Instrument Simulator (IIS) with data compression capability. The IIS will generate imaging data, compress the data, format the data into variable length packets, and deliver the data to the CHRP testbed. This testbed will be used with TDRSS to demonstrate lossless image data compression.

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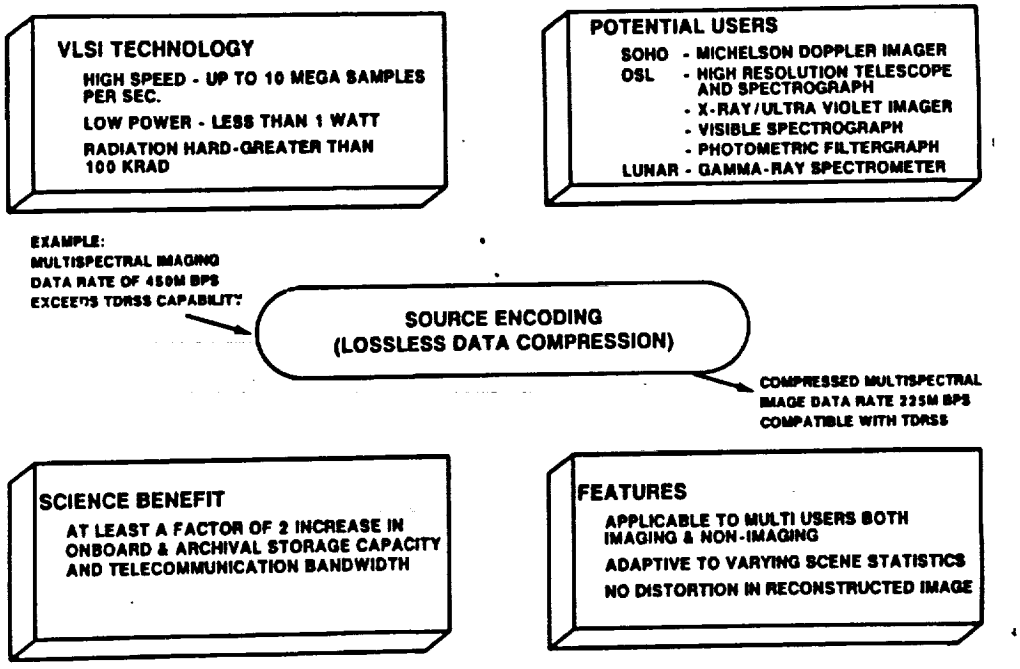
Source Encoding



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Data Storage Technology

The purpose of this task is to evaluate the state of magnetoresistive (MR) fixed-tape head technology for achieving high data rate and high-capacity data storage and to identify an attractive method for simultaneously achieving high data rate and high-capacity recording with high reliability, effective data rate matching, and low mass, volume, and power.

The evaluation results indicate that MR head technology is an extremely viable and promising technology, and that storage density using MR head technology is at least three times greater than optical storage densities. Results also indicate that reliability figures using MR heads are one to two orders of magnitude greater than those achieved with rotary head tape recorders. MR heads can be developed to achieve 300 Mbps and terabit storage in tape recorder formats with low mass, volume, and power. Additionally, high-performance and compact memory modules can be designed that offer higher performance than block access optical and magneto-optical disk drives. Communication has been established with corporations that include Applied Magnetics, IBM, Kodak, Odetics, and Storage Tek, and discussions are under way to support NASA technically in our follow-on FY 1991 baseline demonstration effort.

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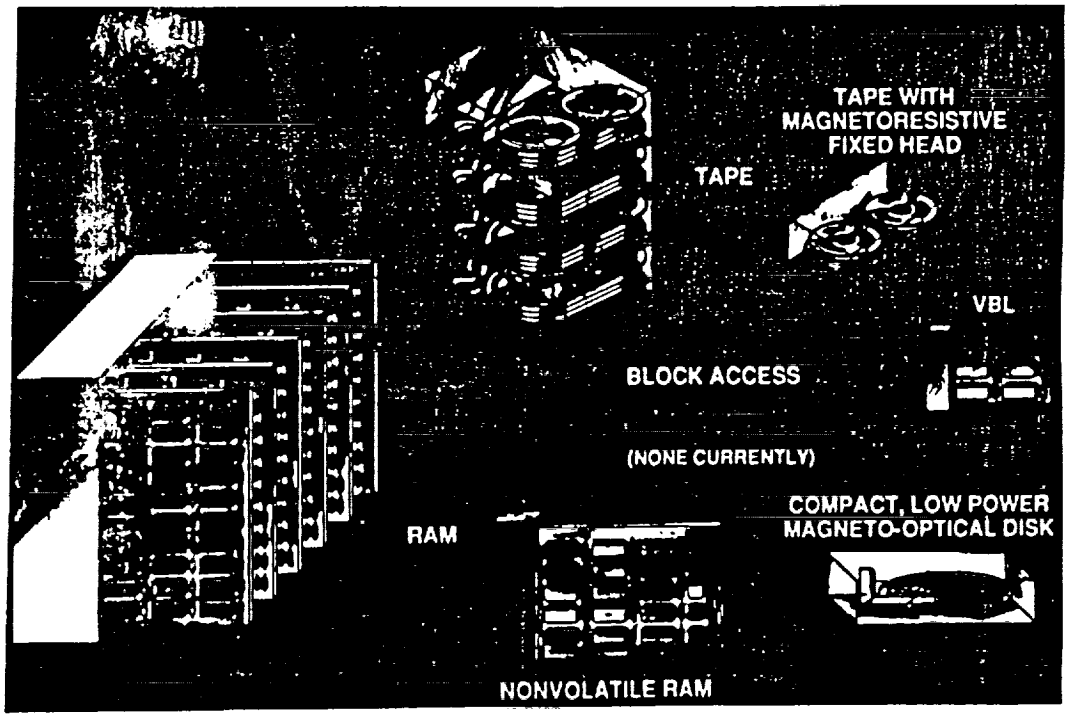
Data Storage for Spacecraft



Imaging Spectrometer Flight Processor — Lossless Data Compressor

The objective of this task is to develop lossless data compression technology for high-rate (up to 500 Mbps) imaging spectrometer focal plane array data for an Earth-orbiting HIRIS mission. Its compression ratio is about 2 to 1. The specific goal is to develop and demonstrate a compressor chip qualified for space by the end of FY 1990.

The unprecedented expanding capabilities of remote sensing imaging systems such as the HIRIS/MODIS has left a big gap in our ability to transmit and store the massive volume of data produced by these systems. In order to utilize the scientific potential of these instruments, without placing unreasonable requirements on telemetry channel bandwidth, a lossless data compression technology must be developed before other high-ratio data compression schemes become available. Such capabilities can enhance the value of advanced NASA space missions from both a science and an operational perspective at minimum cost.

Future Earth-viewing EOS HIRIS systems and planetary flight missions, even in the experimental states, produce large data volumes that tax heavily both the telemetry channel and the storage unit. On-board lossless data compression will reduce by a factor of two the (1) instrument data rates/volumes; (2) instrument data storage requirements; and (3) instrument data downlink requirements. Furthermore, the Very Large Scale Integration (VLSI) implementation will result in reducing the chip count by a factor of five and the system power by a factor of three. Another significant benefit of lossless data compression is more effective ground transmission.

Both the detailed algorithm definition and the performance evaluation of the lossless data compression schemes have been accomplished, and the VLSI design, layout, simulation, and fabrication have been completed. Major milestones for the reminder of FY 1990 consist of finishing testbed fabrication, checkout, and the compressor chip demonstration.

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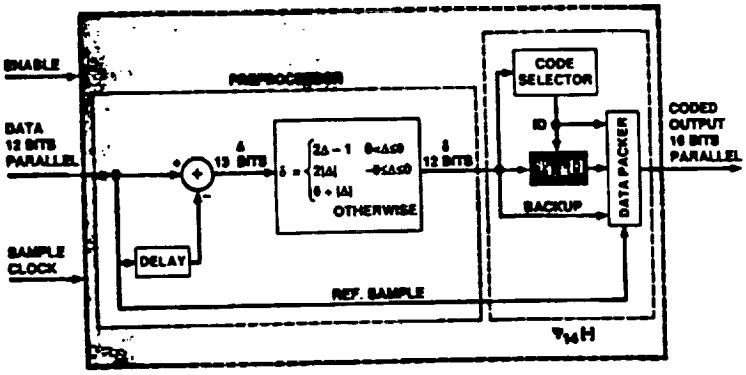
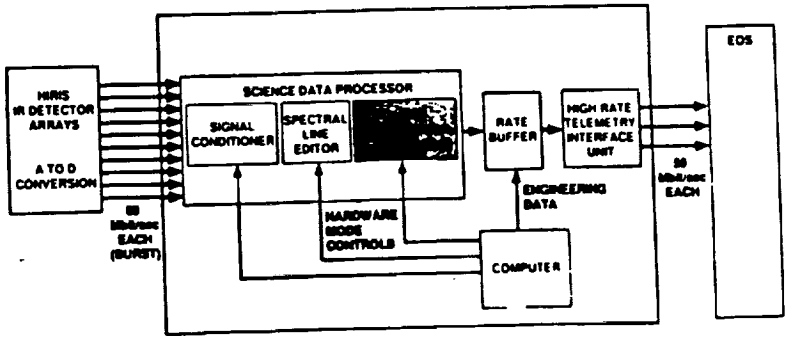
CHIP Functional Block Diagram



HIRIS Command and Data Subsystem



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MAX: Flight Multicomputer

The focus of this program is to develop a real-time, general-purpose computing system and environment that addresses the high reliability needs of interplanetary spacecraft and planetary rovers. MAX is a fault-tolerant parallel-computing architecture specifically adapted to tight resource limitations. It has been designed to support a large, heterogeneous collection of tasks in an unpredictable, event-driven environment, and is easily reconfigurable to a wide range of mission requirements.

On-board computational processing technology has unique requirements and constraints. In order to keep costs down and make optimal use of the available hardware without sacrificing reliability, the MAX architecture was developed. MAX consists of any number of conventional computing elements connected via a dual network topology. One network operates as the prime data highway between these elements and I/O, the other as a broadcast medium that synchronizes tightly coordinated real-time events and tasks. Orchestrating these elements is a very high level operating system that allows these tasks to execute in a highly nondeterministic, event- and data-driven environment while maintaining appropriate redundancy for increased reliability.

With the advent of new high-performance spacecraft processors developed by DoD, integrated autonomous spacecraft operation is now possible. The MAX architecture leverages these new device capabilities into a unique system-oriented approach based on hardware resource pooling. This approach maximizes the utility of available hardware and software resources in order to minimize system mass, power, and volume without compromising reliability.

In 1990, the MAX program continued implementation of fault-tolerant features and of software development tools. A MAX system with three computing modules has been delivered to ARC for independent evaluation. Redundant execution of critical application code with voting of results has been implemented and tested. Very Large Scale Integrated Circuit (VLSI) implementation of the MAX interprocessor communication controllers has begun. A demonstration application that controls an autonomous planetary rover is being developed.

JPL and LaRC have developed a joint plan and specification for the COSMOS computer system, which will combine and build on their experience with dataflow control of multiprocessor systems. This system will use Very High Speed Integrated Circuit (VHSIC) components developed under DoD sponsorship and is projected to handle the foreseeable general-purpose computing needs of NASA missions as well as those of JPL.

FY 1991 plans include completion of the VLSI communications chips and the MAX software tool set. Plans also include starting the implementation of COSMOS on MAX hardware.

Technical Contact
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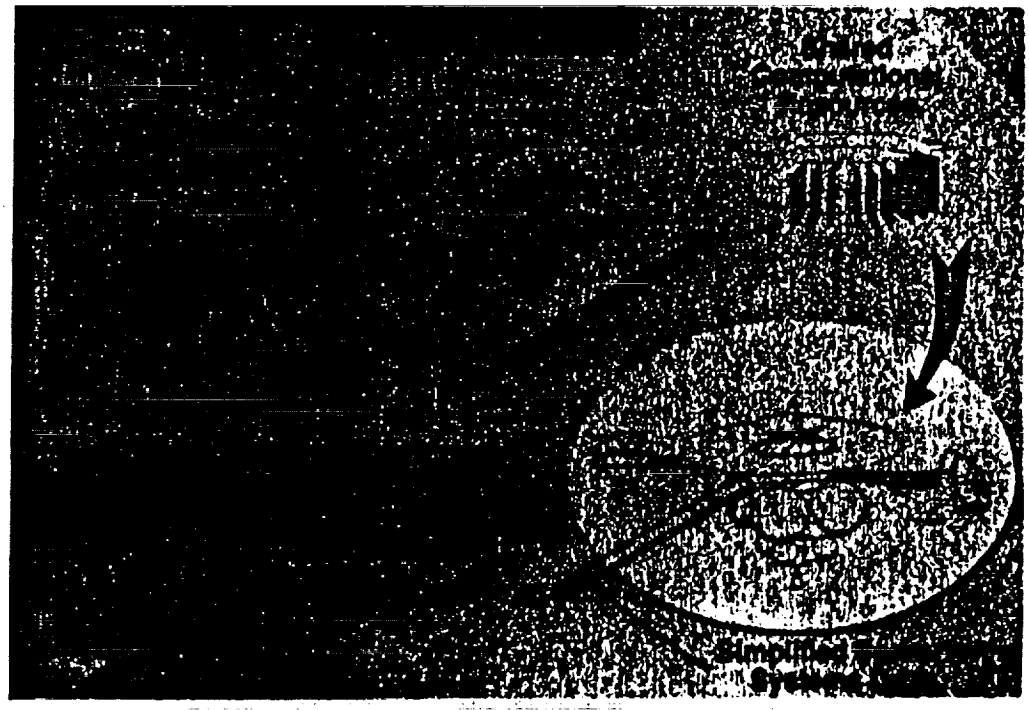
MAX Architecture



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Evaluation of ATAMM Performance on VHSIC Multiprocessor

The objective of this program is to implement the Algorithm to Architecture Mapping Model (ATAMM) on a general-purpose multiprocessor system fabricated with Very High Speed Integrated Circuit (VHSIC) technology to evaluate the performance of the initial ATAMM concept and to identify enhancements to ATAMM to advance the state-of-the-art for real-time spaceborne processing.

A concurrent processing strategy, the ATAMM provides for the dynamic assignment of the nodes of a large grain application algorithm graph to identical processors of a multiprocessor system in a manner that optimizes the execution of the graph. This research integrates the ATAMM rules into an Air Force-developed 1750A Advanced Develop Model (ADM), containing four parallel processors interconnected on a common bus, and it tests the ATAMM strategy. An input/output scheme uses the system's 1553B interface to pass simulated data in and out of the system and to capture important events, time-marking the detailed execution of the nodes of the algorithm graph during execution. Using the time-marked information, detailed performance of an application algorithm is then analyzed and compared with that determined from separate ATAMM simulations. An algorithm coded in Ada and time-simulated algorithms are used to characterize system performance.

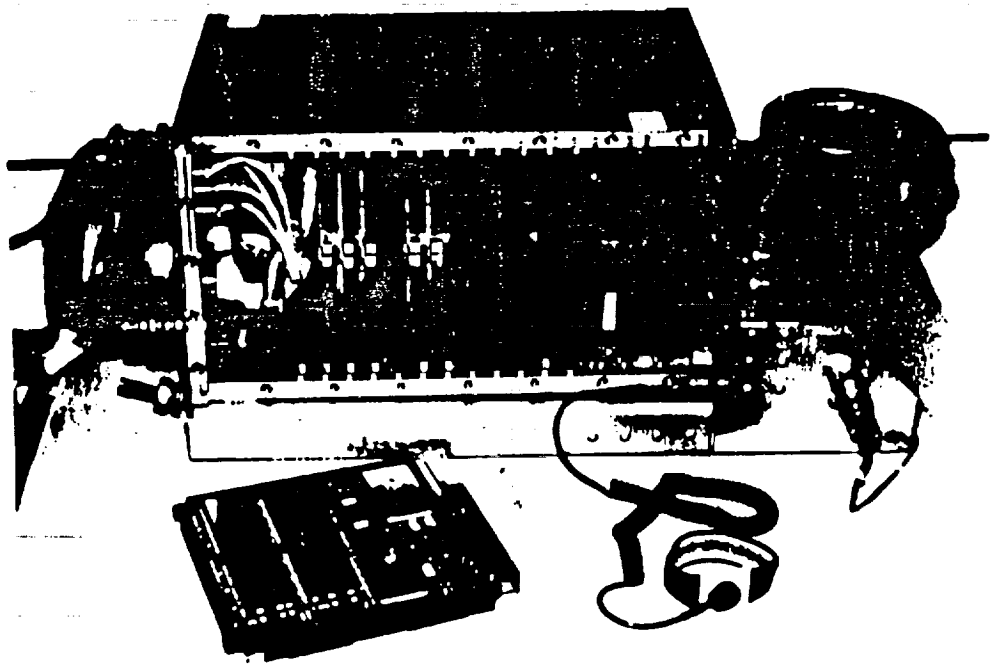
The ATAMM rules were successfully integrated into the Kernel Operating System (KOS), which provides the basic communication functions for the ADM, and the analyzer playback software was completed. The implementation included the intermixing of processor self-testing with algorithm execution. A test interface method was developed to evaluate the performance of the time-simulated graphs and the Ada test algorithm to verify the viability of the ATAMM approach. The integration of the ATAMM software into the hardware was begun to facilitate full ATAMM performance characterization.

The major software developments and the nonintrusive test interface approach are key elements to enable the final integration, debugging, and testing of the ATAMM multiprocessing strategy in an available VHSIC hardware system. The intermixed self-testing approach enhances the likelihood that only healthy processors will be assigned to execute nodes of a graph and that faulty processors can be automatically excluded (or replaced) and taken off-line for further testing.

Debugging of the integrated ATAMM Multicomputer Operating System on the ADM will be completed and the ATAMM methodology tested. ATAMM will be enhanced in the future to broaden its applicability to a wider class of graph situations including multiple graphs, multiple instantiations of the same graph, multiple processor types, and statistical node-latency times. These enhanced versions of ATAMM will be evaluated in spaceborne VHSIC systems and then incorporated into a joint JPL/LaRC operating system for potential future NASA missions.

Technical Contact
Paul J. Hayes, LaRC, (804) 864-1491

VHSIC Multiprocessor Flight Brassboard



SODR Controller Development

The objective of this companion program to the Spaceflight Optical Disk Recorder (SODR) development program is to develop a versatile, modular controller that, when combined with SODR disk drive modules, will provide high-performance mass storage systems that meet NASA high-rate, high-capacity spaceflight needs of the 1990s and beyond. The goal is to develop a system with a capacity of greater than 1 terabit (120 gigabyte), up to a 1.8 gigabit-per-second input and output rate, and configurable, expandable architecture to satisfy various applications.

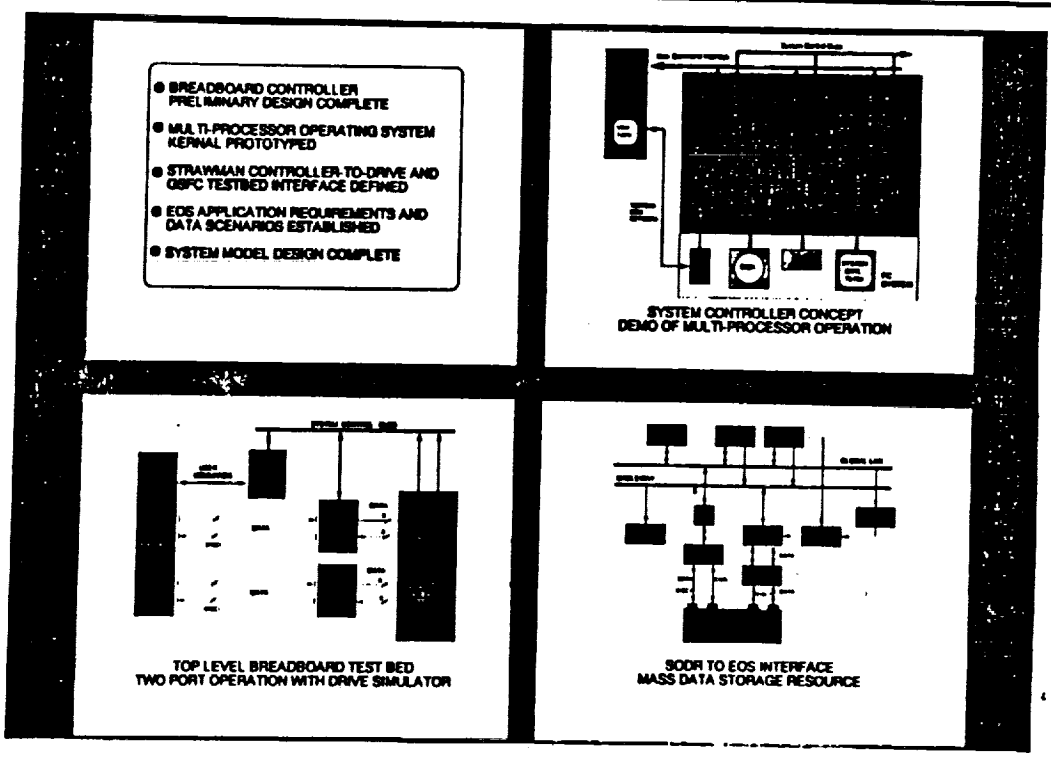
The controller is the enabling element of a versatile recorder. The thrust of this program is to develop a system architecture and controller that allows development of a generic drive unit and provides application-specific user interfaces and expansion in rate and capacity. The focus of the program is application aboard polar-orbiting platforms in support of the Earth Observing System (EOS).

A phased development is planned from breadboard through engineering development and flight qualification. The current emphasis is breadboard design and demonstration of a 2-port operation at 150 megabits-per-second simultaneous read and write or 300 megabits-per-second read or write. This includes verification of system concepts, establishment of operational guidelines, and definition of user interfaces and commands. Breadboard development will culminate in integration with a brassboard drive unit and testbed system demonstration.

During the past year, breadboard controller development has continued. The preliminary design was completed and culminated in a successful design review, which was attended by government cosponsors and representatives from GSFC. A prototype multiprocessor operating system kernel has been developed and tested. Plans have been formulated and the interface defined for demonstration in a GSFC testbed. EOS application requirements have been established, and a strawman interface and operation scenarios have been defined. Since it is not feasible to breadboard a complete system, a system modeling activity has been included. The model design is complete, and coding has begun.

Technical Contact
Thomas A. Shull, LaRC, (804) 864-1837

SODR Controller Development



Spaceflight Optical Disk Recorder (SODR)

High-rate, high-capacity data storage has been identified as an enabling capability for future NASA missions including Earth observation, geostationary missions, and planetary exploration in the 1990s and beyond. The SODR program has been established to develop components and subsystems based on rewritable optical disk technology, which forms the basis for high-performance, mass storage systems. There are three technology development areas: 14-inch magneto-optic (MO) media; multielement diode laser arrays; and a multitrack electro-optic head assembly. Feasibility was demonstrated in 1988 and the FY 1990 goal to demonstrate a full eight-track recording has been achieved. Written data are shown in the polarized microscope photo of the "mark" on the media. This represents a 133-megabit per-second data transfer rate and 5-gigabyte (4×10^{10} bit) capacity on one disk surface exceeding the rate and capacity of any other known disk data storage device.

Also during the past year, a new laser structure was developed that enables more efficient (generating less heat), thus longer-lived devices. Samples have been delivered and are under test at LaRC. A nine-element laser has exceeded 1,000 hours of burn-in (at David Sarnoff Research Center). Glass substrate media have been produced and undergone environmental testing, and media performance optimization for harsh environments is proceeding. This technology is directly transferable to a companion Air Force program. A NASA-sponsored NIST/NASA/DoD/industry working group has been formed to establish rugged 14-inch MO media test standards.

An associated modular controller is being developed at Langley to produce a configurable, expandable system supporting the use of multiple drive modules to obtain data rates in excess of 1 gigabit-per-second (a rate that exceeds any other known or planned optical recording device or flight tape recorder) and capacities up to 1.2 terabits (160 gigabytes).

The current work represents significant technology risk reduction toward development of a completely flight-qualified optical disk drive and controller. NASA and Navy funding are being used to initiate procurement of a brassboard drive unit for flight demonstration in FY 1994.

Technical Contact
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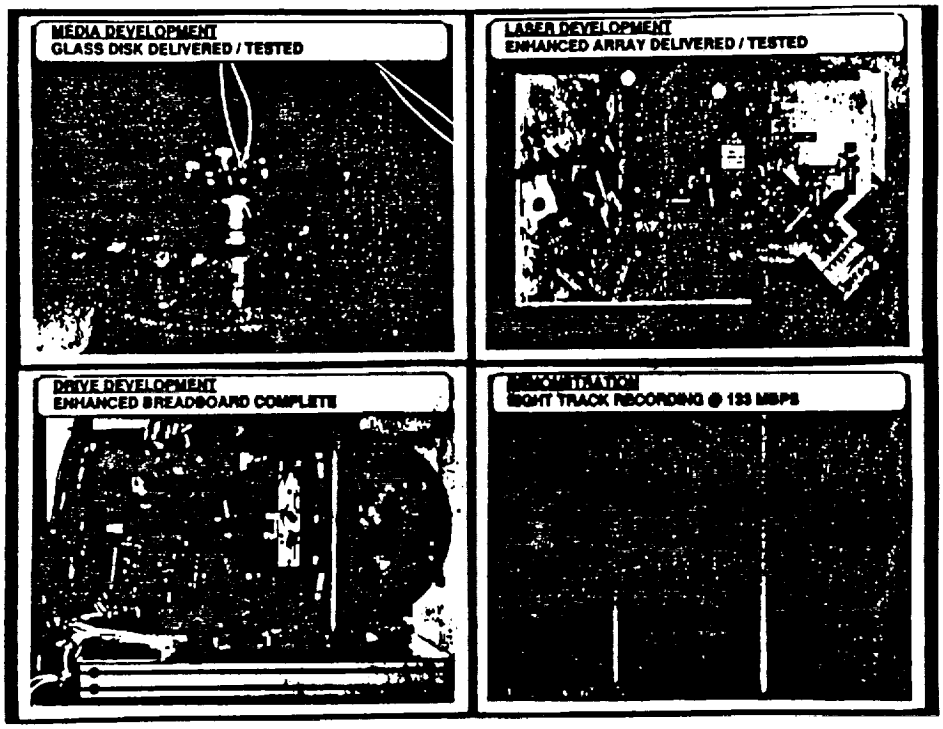
SODR Program Accomplishments



Computer Sciences

The overall goal of the Computer Science Research Program is to foster the advancement of computing technology targeted at aerospace applications. This goal is being realized through a program of basic research and experimentation that focuses on developing core skills within the Agency in disciplines critical to NASA and on maintaining a strong university base of fundamental research in aerospace computer science.

The research program is improving the state of knowledge of fundamental aerospace computing principles. Computing technology in crucial space applications, such as software engineering for very reliable systems and information extraction from data collected by scientific instruments in space, is also being improved.

The program includes the development of special algorithms and techniques to exploit the computing power provided by high performance parallel processors and special purpose architectures. Problem areas of importance include computational fluid dynamics, computational chemistry, structural analysis, signal processing, and image processing. The computer architectures of interest include common and local memory multiprocessors, single-instruction stream/multiple data stream processors, static data flow processors, systolic arrays, and heterogeneous multiprocessors with custom processors. Research is conducted in programming languages and environments, parallel and distributed operating systems, and performance measurements.

Research is also being conducted in the fundamentals of data base logic. This work has resulted in the development of a common user interface for accessing data from several data bases even when the data bases being accessed have very different structures. This work provides the foundation that will enable NASA space data users access to multiple data bases independent of the physical distribution or structure of the data bases. This work will reduce the cost of such investigations and enable data base intensive scientific research that would otherwise be unaffordable. Other work is under way to develop and test an expert system that can serve as an assistant to researchers analyzing space-derived data.

Research is being conducted to improve techniques for producing reliable computing systems. That work is directed at both reducing the number of faults in software and making systems that are tolerant to faults. New approaches and methods for software management and engineering have been devised and are now being evaluated under real working conditions. In addition, emphasis is being placed on the automatic reuse of software to lower software production costs. Future objectives in a new software engineering initiative will include research on the theoretical foundation and extending and evaluating approaches for developing reliable complex software.

The Computer Sciences Program is coordinated with the Space Station's Software Support Environment (SSE) and the DoD-sponsored Software Engineering Institute (SEI) and ADA. NASA also participates with DoD and other national bodies on several advisory and technical coordination committees.

Program Manager: Paul H. Smith, (202)453-2753
Paul Hunter, (202)453-2704
NASA/OAET/RC
Washington, DC 20546

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Empirical Investigation of Sparse Distributed Memory Using Discrete Speech Recognition

The primary purpose of this research is to use discrete speech recognition to identify factors that affect the performance of Sparse Distributed Memory (SDM) for highly correlated data.

The original theory of SDM assumed, for mathematical convenience, that data were distributed uniformly throughout the address space. This assumption is invalid for real-world data.

A progressive series of experiments using spoken digits demonstrates the efficacy of several adaptations of SDM for dealing with real-world data: e.g., error-correcting codes for labels, speech patterns used to determine placement of memory cells, a conservative write rule, choice of appropriate SDM model — the selected-coordinate design worked best. Simulations using these adaptations showed dramatic performance improvements: from 49.6% to 99.3% accuracy on the test sets.

The experiments reveal the importance of matching details of memory architecture to the data of interest and to the scheme for encoding the data as binary patterns.

We plan to extend our research to use continuous-speech to probe SDM performance issues for time-varying phenomena.

Technical Contact
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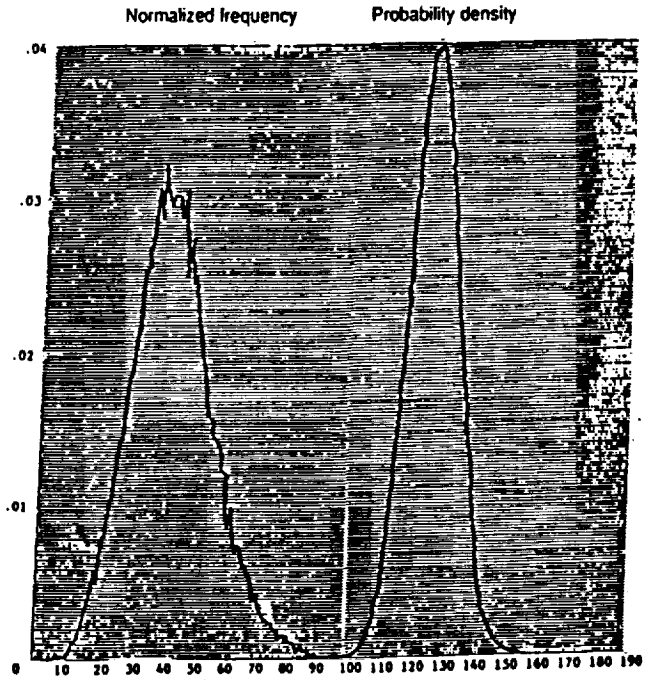
Discrete Speech Recognition Frequency Distribution



The curve on the left is the within-class distribution of digits. For example, various utterances of the digit "1" were encoded as binary patterns and compared to each other in terms of Hamming distance; then the frequency as a function of Hamming distanced was tabulated. Similar tabulations for the other digits were pooled, with the results illustrated by the curve on the left. The binomial distribution on the right illustrates the expected frequency if the digits were randomly distributed in accord with the assumptions of the basic SDM model. The means are separated by 11 standard deviations.

Formal Verification of a Fault-Tolerant Clock Synchronization Algorithm

The objective of this program is to perform a mechanically assisted formal verification of a fault-tolerant clock synchronization algorithm.

The reliability of a fault-tolerant computer system depends critically upon adequate synchronization between its redundant processors. It is important that the synchronization algorithm maintain proper synchronization of the good clocks even in the presence of other faulty clocks. Currently, ad-hoc techniques are used to develop the synchronization system of a fault-tolerant system. Unfortunately, synchronization systems can appear to be sound under a careful Failure Modes and Effect Analysis (FMEA) yet be susceptible to subtle failures. This work provides a formal mathematical basis for an existing algorithm.

The algorithm was defined using the Extended Special Language, which is based on typed, first-order predicate calculus extended to include higher-order constructs and lambda expressions. Using the EHDM (Enhanced Hierarchical Design Methodology) (mechanical) theorem-proving system, it was proved that the algorithm maintains the clocks within a bounded skew.

The Interactive Convergence Clock Synchronization Algorithm was verified. The formal verification process discovered several flaws in the original informal proof of the algorithm, even through the published data were unusually precise and detailed. The theorem was modified and successfully verified.

The performance theorem originally published was found to be flawed. These flaws were not discovered by the informal peer scrutiny to which the paper has been subjected since its publication. Clock synchronization algorithms are extremely important components of a fault-tolerant system yet are surprisingly easy to verify. This project provides another illustration of the increasing capabilities of formal verification methods. The clock synchronization problem is an asynchronous system that historically has posed difficulties for the formal methods approach.

The clock synchronization algorithm will be implemented in hardware and software. The correctness of the detailed design will be formally verified.

Technical Contact
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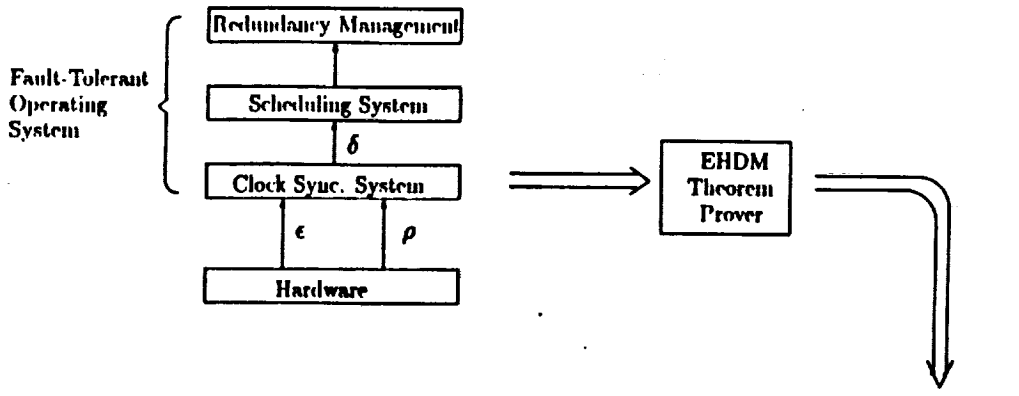
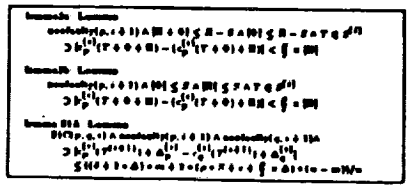
John Rushby and Frieder von Henke, SRI International

Formally Verified Fault-Tolerant Clock Synchronization



δ = clock skew bound
ϵ = clock read error bound
ρ = clock drift rate bound



Mapping Unstructured Grids to Hypercubes

The purpose of this research is to significantly increase the throughput for solving unstructured grid problems on massively parallel computers by reducing the communication time. Current focus is on the Connection Machine (CM).

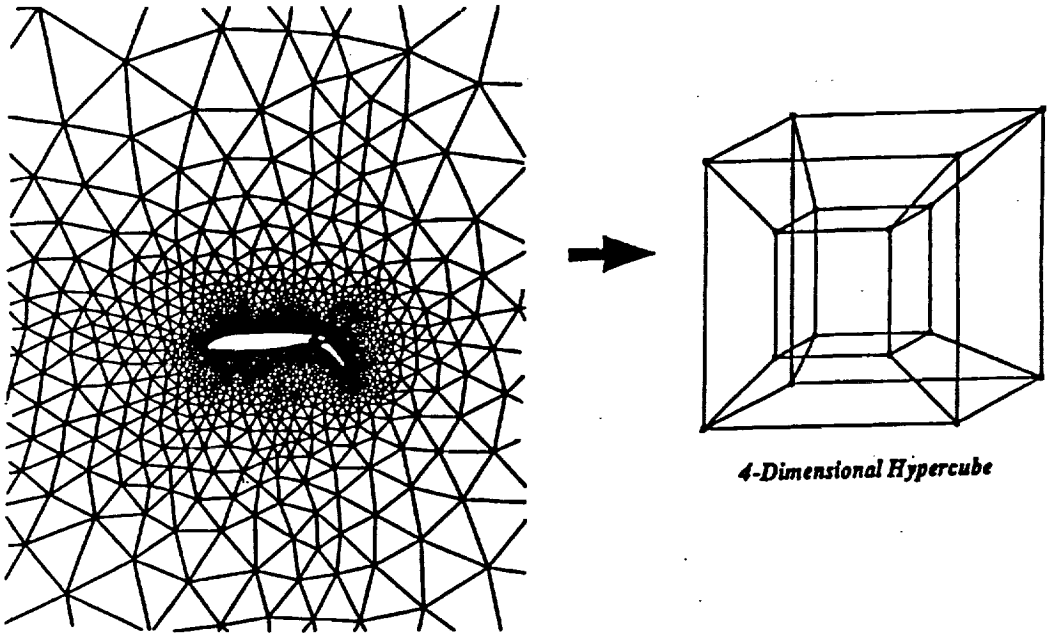
We have developed a highly parallel graph-embedding technique and implemented it on the CM-2. It enables one to efficiently solve unstructured grid problems on massively parallel computers with regular interconnection topologies. The graph of the irregular problem is embedded into the graph representing the interconnection topology of the computer so that communicating processes are assigned to nearby processors.

Many implicit and explicit methods for solving discretized partial differential equations require each point in the discretization to exchange data with its neighboring points every time-step or iteration. Thinking Machines Corporation has recently developed a new software package that reduces the time for general communication by a factor of 2 to 5. This mapping further reduces the communication time by a factor of 3.

Future activities include implementing a CFD application on the CM-2 for comparison with a similar application on the Cray YMP.

Point of Contact
Steven Hammond, ARC (RIACS), (415) 604-3962

Map Irregular Problem to Regular Interconnection Topology



4-Dimensional Hypercube

Performance Characterization of Machine Architecture

The main objective of this project is to develop a new methodology for the evaluation of different machine architectures and implementations. The idea is to construct a model of a machine based on its execution time for source language program constructs. Separately, one analyzes relevant source codes; by combining the analyses, one can evaluate the performance of any analyzed machine for any analyzed workload. Our efforts have been directed toward experimental methods for accurate machine characterization (the machine model), methods to maximize the accuracy of our performance predictions, and the use of the machine characterizations to analyze implementations and architectures.

Our research has produced a number of significant results: (a) Our methodology permits the evaluation of CPU performance with far less benchmarking effort than was previously needed. (b) Using our methodology, one can see why the observed performance occurs. Strong and weak points of various implementations can be determined and evaluated. (c) The variability of performance observed between two machines when run on a variety of benchmarks can be predicted and explained. (d) The sensitivity of a given machine's performance to variations on the workload can be explained and predicted. (e) The effect of improvements in machine performance can be predicted. (f) Our techniques can be used to characterize workloads.

The present status of this project is as follows: (1) We have developed a machine performance model consisting of 113 parameters which have been measured on a large set of machines ranging from supercomputers to high-performance workstations. (2) A large set of applications have been characterized; these include the SPEC and Perfect Club benchmarks. Our results show the strength and weaknesses of these programs, and our methodology will help in the development of more representative benchmark workloads. (3) We have used the machine and program characterizations to validate our model by making execution time predictions and comparing these results with actual measurements. Very good accuracy has been observed. (4) We have investigated how our model can be used to compare the differences and similarities of machines and programs; we have proposed a set of metrics and have presented the results in reports and papers. (5) We are developing a set of experiments to characterize compiler optimization, and we are currently extending our execution time model to include the effect of optimizing compilers. (6) We have used our model to estimate the potential performance of the NEC SX-3 with respect to the performance of the NEC SX-2 and CRAY Y-MP/8128.

We plan to continue this project with the activities described above as "in progress," and by extending our model to include vector operations. A new machine characterizer will include a large number of experiments that will measure the performance of vector operations. In addition, we will extend our execution time model to produce approximate execution times for programs that use vector operations. We are investigating the applicability of vector performance prediction models to complement our scalar execution time prediction method.

Technical Contact
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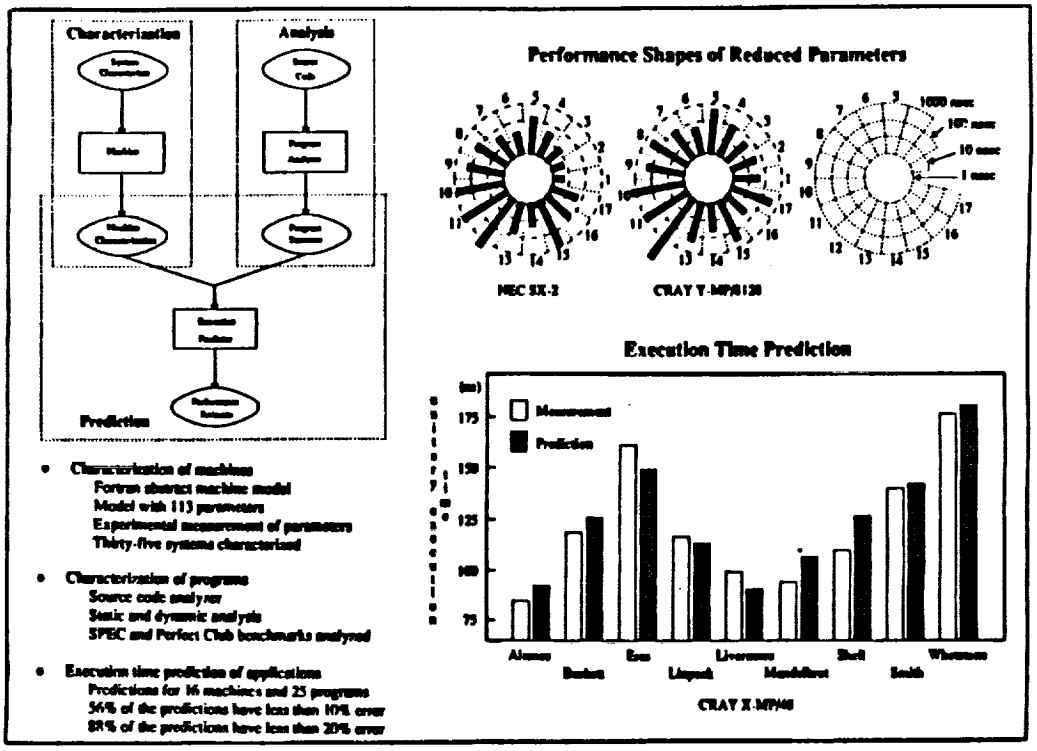
Performance Characterization of Machines



- Characterization of machines
  - Fortran abstract machine model
  - Model with 113 parameters
  - Experimental measurement of parameters
  - Thirty-five systems characterized
- Characterization of programs
  - Source code analyzer
  - Static and dynamic analysis
  - SPEC and Perfect Club benchmarks analyzed
- Execution time prediction of applications
  - Predictions for 16 machines and 25 programs
  - 56% of the predictions have less than 10% error
  - 88% of the predictions have less than 20% error

Performance Evaluation of an Implicit CFD Algorithm on a MIMD Hypercube

The objective of this program is to evaluate the performance of an implicit computational fluid dynamics (CFD) algorithm on a distributed-memory, multiple instruction stream, multiple data stream (MIMD) architecture. We plan to implement the functionality of ARC2D (2-D Euler/Navier-Stokes) code on the 128-node Intel Touchstone Gamma prototype (commercially known as the Intel Personal Supercomputer, model 860 [iPSC/860]).

The algorithm has been successfully mapped to the Touchstone architecture, and considerable effort was put into optimizing the code for the machine. In spite of the current FORTRAN compiler's inability to exploit pipelined arithmetic units on the i860 chip, overall performance and multiprocessor efficiencies appear promising. Current performance levels are below that of the single processor Cray Y-MP, but they are comparable to that of the Cray-2 and the Connection Machine (CM-2). The inadequate bandwidth of the data path to the node memory and of the internode communication network will continue to pose problems for implicit algorithms.

This work demonstrates that implicit CFD algorithms can be implemented on highly parallel distributed-memory MIMD architectures. It also identifies the architectural bottlenecks preventing the exploitation of the full performance potential of pipeline-reduced instruction set computing (RISC) chips. Removal of these bottlenecks will result in implementations of implicit CFD codes being implemented with sustained high performance and good scalability.

The ARC2D study will be completed by documenting the implementation details and results in a formal publication. Implementation of a 3-D implicit Navier-Stokes code (F3D) is currently under way. Issues related to the exploitation of functional parallelism, in addition to the data parallelism present in multiple overlapping grid applications, will be explored. The possibility of using implicit algorithms more suited for parallel processing with stronger convergence rates will be investigated as an alternative to the approximate factorization method.

Technical Contact
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Comparison of ARC2D Performance

NAVIER-STOKES CODE

Problem Size		Intel Touchstone							Cray-2	Cray Y-MP
		No. of Processors								
		1	2	4	8	16	32	64		
(192X64)	Sec./step	4.1	2.1	1.11	0.61	0.35	0.22	0.14	0.15	0.08
	MFLOPS	3.0	5.9	11.2	20.3	35.6	56.7	86.4	82	163
	Efficiency(%)	-	98	92	83	73	58	44	-	-
(256x80)	Sec./step	-	3.49	1.82	0.98	0.54	0.33	0.20	0.26	0.13
	MFLOPS	-	6.0	11.4	21	39	64	101.	79	161
	Efficiency(%)	-	99	95	88	81	67	53	-	-
(320x128)	Sec./step	-	-	3.62	1.90	1.02	0.57	0.34	0.48	0.24
	MFLOPS	-	-	11.6	22	41	73	123	86	172
	Efficiency(%)	-	-	97	92	85	76	64	-	-

EULER CODE

Problem Size		Intel Touchstone							Cray-2	Cray Y-MP
		No. of Processors								
		1	2	4	8	16	32	64		
(192X64)	Sec./step	3.58	1.87	1.00	0.55	0.32	0.20	0.13	0.14	0.07
	MFLOPS	3.0	5.8	10.8	19.7	33.8	54.2	83.3	75	158
	Efficiency(%)	-	96	90	81	70	56	43	-	-
(256X80)	Sec./step	-	3.12	1.64	0.88	0.49	0.30	0.19	0.26	0.13
	MFLOPS	-	5.8	11.1	20.6	37.0	60.5	95.5	74	158
	Efficiency(%)	-	96	93	86	77	63	50	-	-
(320x128)	Sec./step	-	-	3.62	1.90	1.02	0.57	0.34	0.48	0.24
	MFLOPS	-	-	11.6	22	41	73	123	86	172
	Efficiency(%)	-	-	97	92	85	76	64	-	-

MFLOPS based on measurements using the Cray hardware performance monitor (hpm).
Efficiency (%)= ((MFLOPS on one processor) / N x (MFLOPS on N processors))*100.

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Two-Dimensional Shape Recognition Using SDM

The focus of this research was to test Sparse Distributed Memory (SDM) for recognizing two-dimensional shapes, using Andrew B. Watson's cortex transform for preprocessing.

A total of 280 random characters were selected from the US Postal Service Database of Handwritten Zip Codes as standard shapes. Half the characters were used to train the memory and half were used for testing. The test results can be compared with results of other groups using the USPS data base.

A preliminary study revealed that the low-pass filter of the cortex transform was suitable for an input representation for SDM. Accordingly, each character was scanned into an 8 X 8 black-white pixel array and filtered, yielding a four-bit gray-scale representation encoded as a 256-bit binary pattern. After training the memory on half the characters, the SDM correctly labeled 86% of the test characters.

The method is very general inasmuch as no special features of written characters were used to improve performance. And it is fast — training requires less than 2 minutes. A system designed for character recognition at Bell Laboratories performed in a comparable measure at 88% correct but used hours of run-time for training.

Future plans are to continue investigating encoding methods, e.g., a very general contour map representation of two-dimensional shapes suggested by Kanerva.

Technical Contact
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The Cortex Transform

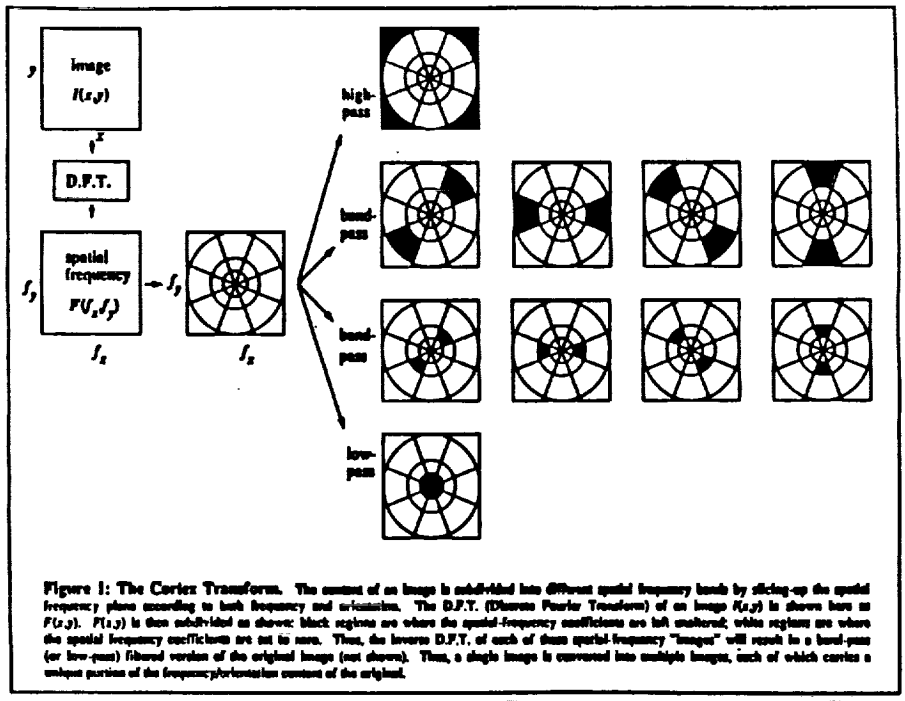

Figure 1: The Cortex Transform. The contents of an image is subdivided into different spatial frequency bands by slicing-up the spatial frequency plane according to both frequency and orientation. The D.F.T. (Discrete Fourier Transform) of an image $I(x,y)$ is shown here as $F(x,y)$. $F(x,y)$ is then subdivided as shown: black regions are where the spatial-frequency coefficients are left unaltered; white regions are where the spatial frequency coefficients are set to zero. Then, the inverse D.F.T. of each of these spatial-frequency "images" will result in a band-pass (or low-pass) filtered version of the original image (not shown). Thus, a single image is converted into multiple images, each of which carries a unique portion of the frequency/orientation content of the original.

Software Management Environment

The Software Management Environment (SME) is a software tool designed to assist a manager in monitoring, analyzing, and controlling an ongoing software project. The SME's major functions include tracking software project parameters; analyzing the differences between the current project's development patterns and the expected development patterns within the application environment; predicting characteristics such as milestones, cost, and reliability; assessing the overall quality of the project's development process; and providing advice and guidance on management of the software project. To provide these functions the tool continually examines available development data from the project of interest including manpower, software changes, computer utilization, and completed milestones and compares this information to data from past projects and to a model of the typical project.

During FY 1990, the SME has been extended and improved to include expert assessment of project problems and to model the project environment. With these extensions in place, the SME has been released for use by software managers within the Flight Dynamics Division at GSFC. By using the SME for ongoing software development projects within Flight Dynamics, the managers will be able to effectively compare, predict, and analyze key project parameters. This represents the first use of the SME on actual projects and will provide valuable insight into the accuracy and usefulness of the tool, as well as help to establish future research needs for the SME.

During the next year, the SME will be prepared for release to other organizations outside of Flight Dynamics. This planned release will begin to establish the usefulness of such a tool in an environment beyond the one for which it was originally designed. Other planned research includes the development of an overall project assessment function and to begin examining ways of providing guidance to managers for solving development problems.

Technical Contact
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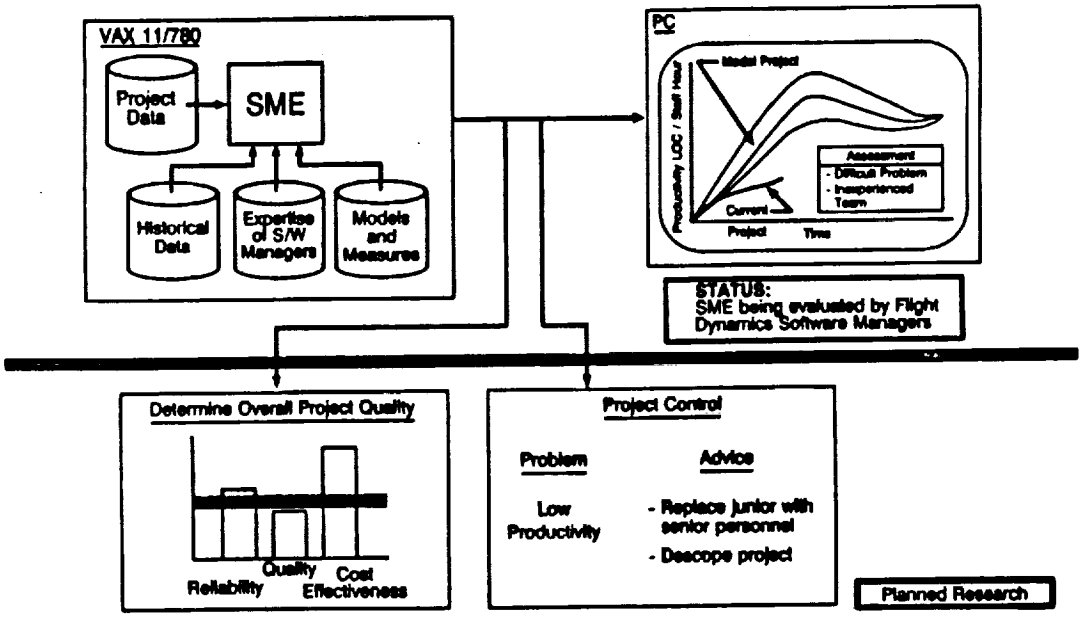
Management of Complex Software Projects



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Autonomous Exploration

Robotic and human exploration to the moon and Mars are anticipated in the coming decades. The robotic missions will serve to perform geological survey and surface characterization to collect samples and to return the necessary information about potential landing sites to enable safe and productive human missions. Vehicles for lunar and planetary exploration will carry complex scientific imaging instruments, including imaging spectrometers capable of collecting data points at several hundred wavelengths for each pixel. To exploit the full capabilities of these instruments, methods must be developed for real-time information extraction, multisensor fusion, and automated decision making to drive instrument reconfiguration. Onboard interpretation of the data from a suite of instruments will be required for site characterization, for collecting samples, and for choosing desired traversal paths on a ground-roving vehicle.

The objectives of this task are to develop and implement autonomous, real-time methods of high-dimensional image data reduction, information extraction, and goal-driven decision making. Data from multiple instruments may be fused to provide a more complete interpretation of a scene. A hierarchical, multiresolution approach in both spectral and spatial domains reduces computational requirements by concentrating the analysis on image areas that prove potentially interesting during initial, low-computation analysis. This approach includes iterative cycles of data acquisition and interpretation, decision making, and instrument reconfiguration.

The working system analyzes both single band imagery (to extract shape and textural information) and multispectral images (to determine geologic composition). The spectral classification steps, performed on simulated neural networks, include assessing classification accuracy so that poorly classified or unknown mineral classes may be handled appropriately. The system has been designed so that at each step in the hierarchical analysis procedure, information from other instruments may be incorporated if available. All available data are used to decide whether to continue examining a region and with what instruments. The system is capable of specifying the spectral bands of importance for the next step in the analysis, so that the imaging spectrometer may be automatically reconfigured.

Although the existing design is primarily aimed at supporting autonomous robotic exploration, many elements will transfer readily to support systems for human exploration. In particular, the analysis and interpretation of multiple complex data sets will still be performed by machine during human exploratory missions. Further development of the existing data analysis system will enable the collection and interpretation of instrument data to provide human explorers with information in a form that will allow them to perform most effectively.

Technical Contact
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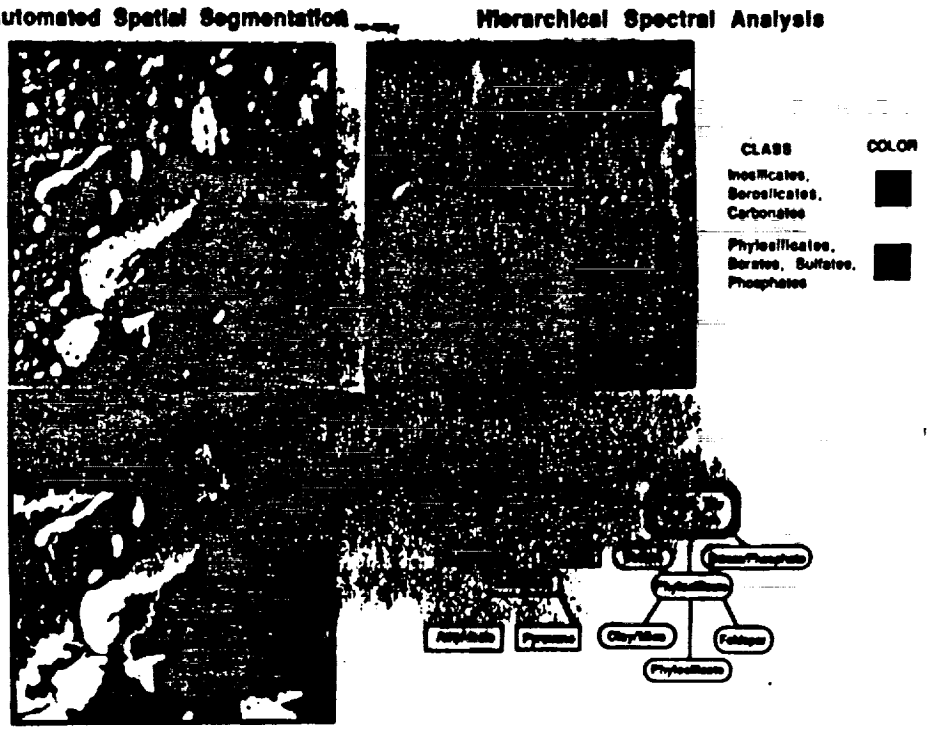
Autonomous Exploration



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Application and Assessment of Industry-Standard Guidelines for the Validation of Avionics Software

The objective of this program is to incorporate industry standards for the development of real-time software into an experimental testbed for studying the failure process of avionics software and assess the effectiveness of methods that comply with those standards.

Verification activities were defined along with configuration management and software quality assurance policies for the development of Guidance and Control Software (GCS) in accordance with the FAA Radio Technical Commission for Aeronautics RTCA/DO-178A guidelines for the certification of avionics software. These verification procedures were applied in the generation and testing of three independent versions of the GCS code. All software error data needed to assess the effectiveness of software development and verification methods and provide the basis for software reliability model development were collected.

Verification and validation activities in accordance with the DO-178A standards for avionics software have been defined and implemented in the development process of the GCS versions. Software error data are being collected throughout the development cycle.

Although many software reliability experiments have been conducted, these experiments have not considered complex avionics software that is critical to mission success. The GCS experiment provides a realistic baseline for investigating the failure behavior of avionics software. Employing the DO-178A guidelines will yield error data from real-time software developed according to industry standards, and the integrity of the error data along with the ability to reproduce it are guaranteed by the implementation of the verification plan. Since adequate models for dependable estimation of software reliability do not currently exist, the error data from the GCS experiment will provide an indispensable basis for improving software reliability models. This experiment further establishes a pragmatic baseline for investigating the effectiveness of development methods, such as those prescribed by the FAA, for avionics software.

The next steps in this program are to complete testing of the three GCS versions and analysis of the resulting software error data and develop more precise software reliability models and more effective software development procedures based on this information.

Technical Contact
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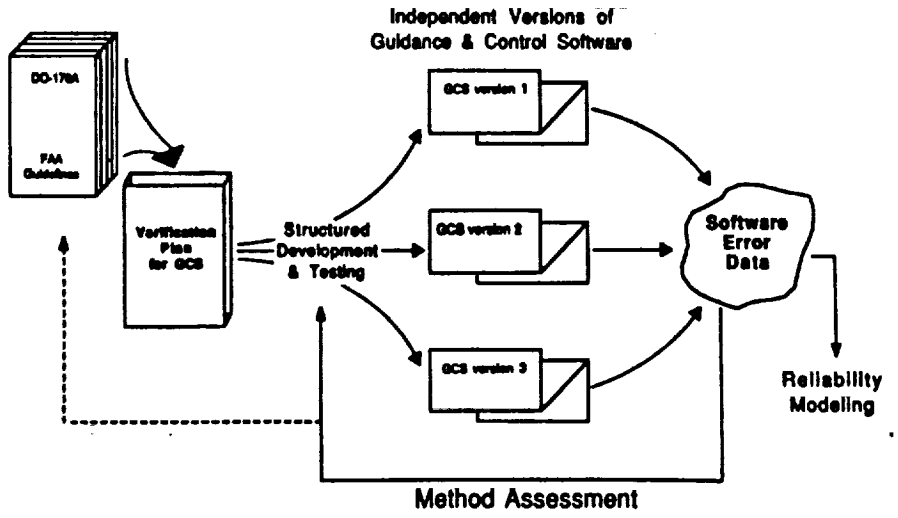
Anita M. Shagnea, Research Triangle Institute

Production of Realistic Software Error Data



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Automatic Generation of ADA Code

The objective of this program is to demonstrate and assess the ability of the Charles Stark Draper Laboratory (CSDL) Computer-Aided Software Engineering (CASE) system to generate ADA flight control code. The Advanced Launch System (ALS) Advanced Development Program is sponsoring the development of a Computer-Aided Software Engineering (CASE) tool by the Charles Stark Draper Laboratory that could dramatically improve the software development process and reduce production and maintenance costs. As a demonstration of this tool, the flight control system software of the Boeing 737 autopilot autoland was produced using the ALS CASE system.

ADA source code and specification documentation were automatically generated with the ALS CASE system. The specifications for the autoland design were reverse-engineered from inspections of FORTRAN flowcharts and source code. The software requirements were interactively specified in the form of hierarchical engineering block diagrams via the system's highly flexible, graphic interface. The requirements defined by these diagrams were checked for data type consistencies by the CASE system and captured in a centralized knowledge base. The knowledge base was then used to automatically produce executable code and a formatted requirements document. A test methodology was developed which maximized coverage but minimized the number of tests. Duplicate tests were run on both the FORTRAN and ADA code and then the results compared. Open and closed loop tests uncovered 11 discrepancies. Nine of these errors were attributed to mistakes in the entry of the specifications into ALS CASE (human errors, analogous to programming errors). Two errors were traced to the FORTRAN code. No errors were traced to the ALS CASE system.

The development and testing of "real" software application, such as the autopilot autoland, will lend much to the credibility of the ALS CASE system. In addition to the two errors found in the FORTRAN code, several ambiguities and inconsistencies were discovered in the specification as a result of using the ALS CASE diagram methodology. ALS CASE has the potential to significantly increase the reliability of the generated code by (1) checking for inconsistencies, ambiguities, and completeness of the specification; (2) allowing the user to specify software using engineering notation and block diagrams that are familiar; (3) automatically performing the usually error-prone transformation to ADA code; and (4) supporting reuse of code. The ALS CASE effort has demonstrated the feasibility of a knowledge-based approach to software development and has identified areas that warrant research to further automate the software development process.

Progress is being made to enhance the ALS CASE system in a number of areas. These include a software design methodology interface, an automated testing facility, and project management capabilities. As a further demonstration, the guidance and control software for the final decent phase of a planetary lander is being generated using the ALS CASE system. This code will be used in a software error-data gathering experiment to be conducted by Langley and the Research Triangle Institute.

Technical Contact
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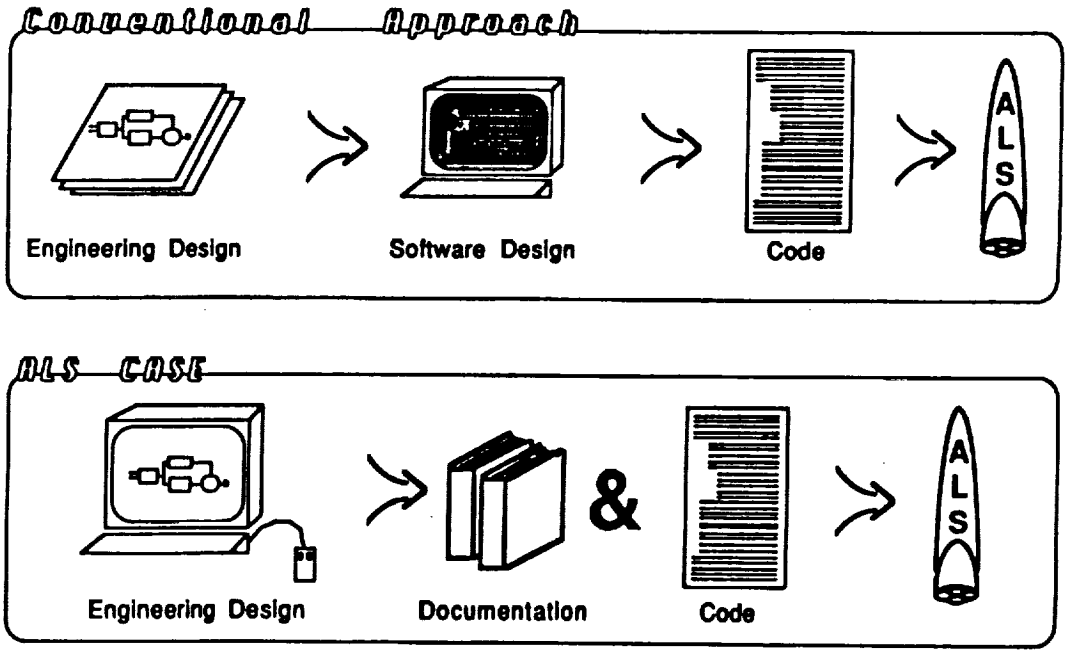
John J. Turkovick, LaRC, (804) 864-1704

ALS Case System



OMIT

SSTAC/ARTS

Communications

Overview of Communications Programs

NASA Headquarters
OAET/Code RC

June 26, 1991

Dr. Ramon P. DePaula

RC

COMMUNICATIONS PROGRAM

OAET

OBJECTIVE:

Advance critical areas of enabling and enhancing communication technologies that support commercial needs, science, and exploration missions for the 1990's and beyond. The technology program consists of research and technology development in:

- RF Technology
- Digital Technology
- Optical Communications
- Mobile Communications
- Systems Integration, Test & Evaluation

RC

COMMUNICATIONS SATELLITE DEVELOPMENT PROGRAM BASIS

OAET

- **NATIONAL AERONAUTICS AND SPACE ACT OF 1958**

  ...Space activities...shall be conducted so as to contribute materially to...

  (4) The establishment of long-range studies of the potential benefits to be gained from, the opportunities for, and the problems involved in the utilization of aeronautical and space activities for peaceful and scientific purposes;

  (5) The preservation of the role of the United States as a leader in aeronautical and space science and technology and in the application thereof to the conduct of peaceful activities within and outside the atmosphere;...

- **COMMUNICATIONS SATELLITE ACT OF 1962**

  "...The National and Aeronautics and Space Administration shall...

  (1) Advise the commission on technical characteristics of the communications satellite system;

  (2) Cooperate with the corporation (Comsat) in research and development to the extent deemed appropriate by the administration in the public interest;...

  (4) Consult with the corporation with respect to the technical characteristics of the communications satellite;..."

RC

COMMUNICATIONS PROGRAM

OAET

HISTORY

1960 — **ECHO I LAUNCH**
- 30-m balloon
- First live, two-way voice via satellite
- First oceanic transmission by satellite

1962 — **COMMUNICATIONS SATELLITE ACT**
- Formalized NASA R&D support

1962, 1964 — **RELAY I, II LAUNCH**
- Carried two 10 W transponders
- Demonstrated live television transmission around the world

1963 — **SYNCOM II LAUNCH**
- Demonstrated station keeping and orbital control principals
- First use of range/range rate tracking
- Demonstrated utility of continuous coverage
- Model for Domsats and four generations of Intelsats

1964 — **ECHO II LAUNCH**
- Proved feasibility of radio transmission
- Demonstrated effectiveness of Earth station equipment

RC

COMMUNICATIONS PROGRAM

OAET

HISTORY (Cont.)

1964 — **SYNCOM III LAUNCH**
- Demonstrated acceptability of 0.5 second delay
- Proved out rocket, spacecraft and communications technologies for commercial use

1966 — **ATS-1 LAUNCH**
- Electronically despun antennas
- Demonstrated multiple-access voice
- Provided facility for testing new applications

1967 — **ATS-3 LAUNCH**
- Mechanically despun antennas
- Hydrazine propulsion for station keeping
- First ground-airplane communications
- First color photo of Earth
- Operations support of Apollo missions

RC

COMMUNICATIONS PROGRAM

OAET

HISTORY (Cont.)

1969 — **ATS-5 LAUNCH**
- Introduced K-band transmitters
- Propagation measurements of fades
- Demonstrated high speed teletype for maritime application
- Measured spacecraft charging in eclipses

1973 — **SATELLITE COMMUNICATIONS R&D DE-EMPHASIZED BY NASA**

1974 — **ATS-6 LAUNCH**
- First body stabilized communications satellite
- Introduced L-band communications
- Introduced 9.1 m multi-frequency antenna
- Demonstrated direct broadcast TV (DBS)
- Provided millimeter wave propagation package
- Tested data relay satellite technology
- Demonstrated networking and data collection using small Earth stations
- Introduced real-time TV to Alaska

RC

COMMUNICATIONS PROGRAM

OAET

HISTORY (Cont.)

1976	CTS (NASA/CANADA) LAUNCH • Advanced body stabilized design • Lightweight, folded solar arrays • 200 W, 12 GHz TWT • Demonstrated broadcast and thin route services to VSAT's
1978	NASA DIRECTED TO RESUME ADVANCED SATELLITE COMMUNICATIONS R&D
1978-1979	LONG RANGE PROGRAM PLAN ESTABLISHED-BEGINNING OF EXTENSIVE NASA/INDUSTRY INTERACTION ON SATELLITE COMMUNICATIONS
1979	GSFC COMMUNICATIONS WORK FOR OSSA ELIMINATED • Lewis designated lead center for satellite communications by OSSA • JPL gets propagation program

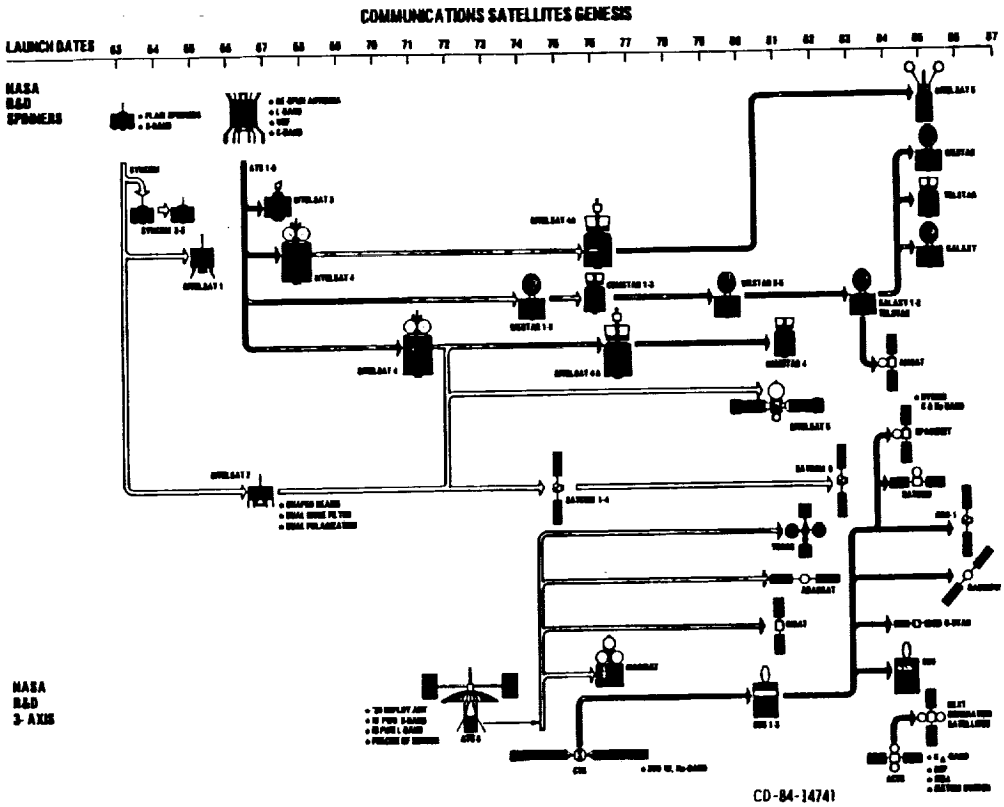
RC

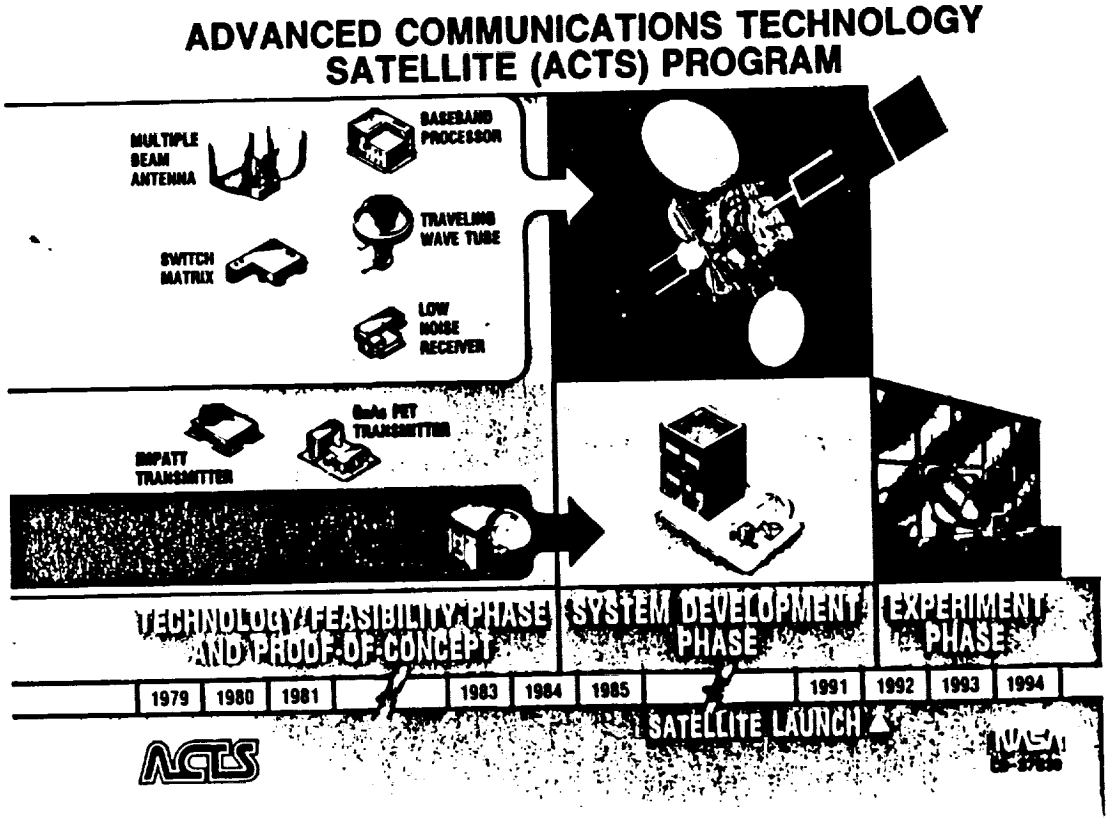
COMMUNICATIONS PROGRAM

OAET

HISTORY (Cont.)

1980	PROOF-OF-CONCEPT TECHNOLOGY DEVELOPED FOR ACTS • Mobile satellite concepts studied
1984	ACTS PROJECT INITIATED
MID 1980s	MSAT-X (Mobile SATellite eXperiment) AND OPTICAL COMMUNICATION DEVELOPMENT INITIATED • MSAT-X technology and field experiments program initiated (JPL)
LATE 1980s-EARLY 1990s	SATCOM DEVELOPMENT PROGRAM BROADENED • MSAT-X technology and field experiments completed • JPL work transitioned to mobile and personal uses at Ka-band • Work begun at Lewis and JPL on high temperature superconductivity • ACTS system CDR in 1990
1991	CODE SC PROGRAM IN SATELLITE COMMUNICATIONS DISTRIBUTED AMONG CODES SE, RC, AND C
1991	CODE RC/OAET BECOMES THE FOCAL POINT FOR COMMUNICATION TECHNOLOGY DEVELOPMENT AT NASA


COMMUNICATIONS SATELLITES GENESIS
LAUNCH DATES
NASA
R&D
SPINNERS
NASA
R&D
3- AXIS
CD-84-14741


ADVANCED COMMUNICATIONS TECHNOLOGY
SATELLITE (ACTS) PROGRAM
MULTIPLE
BEAM
ANTENNA
BASEBAND
PROCESSOR
TRAVELING
WAVE TUBE
SWITCH
MATRIX
LOW
NOISE
RECEIVER
IMPATT
TRANSMITTER
TECHNOLOGY FEASIBILITY PHASE
AND PROOF OF CONCEPT
SYSTEM DEVELOPMENT
PHASE
EXPERIMENT
PHASE
1979
1980
1981
1983
1984
1985
1991
1992
1993
1994
SATELLITE LAUNCH
ACTS

RC

COMMUNICATIONS PROGRAM

OAET

APPROACH:

- IDENTIFY TECHNOLOGY NEEDS THROUGH STUDIES, FUTURE MISSION REQUIREMENTS AND GUIDANCE FROM THE SSTAC AND SPACE COMMUNICATION STEERING COMMITTEE
- IDENTIFY THE CENTERS WITH THE BEST CAPABILITIES AND FACILITIES FOR THE IDENTIFIED TECHNOLOGY AREAS
- DEVELOP A COORDINATED PROGRAM USING INPUTS FROM CENTERS AND NASA HEADQUARTERS
- ESTABLISH PARTNERSHIPS BETWEEN THE CENTERS, INDUSTRY, UNIVERSITIES, AND OTHER LABORATORIES
- BASE PROGRAM ELEMENTS DEMONSTRATE LABORATORY PERFORMANCE OF COMPONENTS/BREADBOARDS
- FOCUSED PROGRAM ELEMENTS HAVE ADVANCED BRASSBOARD DEMONSTRATION WHICH IS THE FIRST STEP IN CONTRIBUTING TO TECHNOLOGY TRANSFER, AND WHEN APPROPRIATE, PARTICIPATE IN COMMUNICATIONS FLIGHT EXPERIMENTS
- TRANSFER TECHNOLOGY TO THE USER FOR DEVELOPMENT OF OPERATIONAL FLIGHT SYSTEMS

RC

COMMUNICATIONS PROGRAM

OAET

BENEFITS:

- CRITICAL ENABLING COMMUNICATIONS TECHNOLOGIES ARE PROVIDED IN ACCORDANCE WITH THE LONG RANGE PLANS OF THE NASA USER COMMUNITY AND U. S. INDUSTRY THAT WILL:
  - **MAINTAIN U.S. PREEMINENCE IN SPACE COMMUNICATIONS TECHNOLOGY**

AND ENABLE THE DEVELOPMENT OF THE FOLLOWING TECHNOLOGIES:

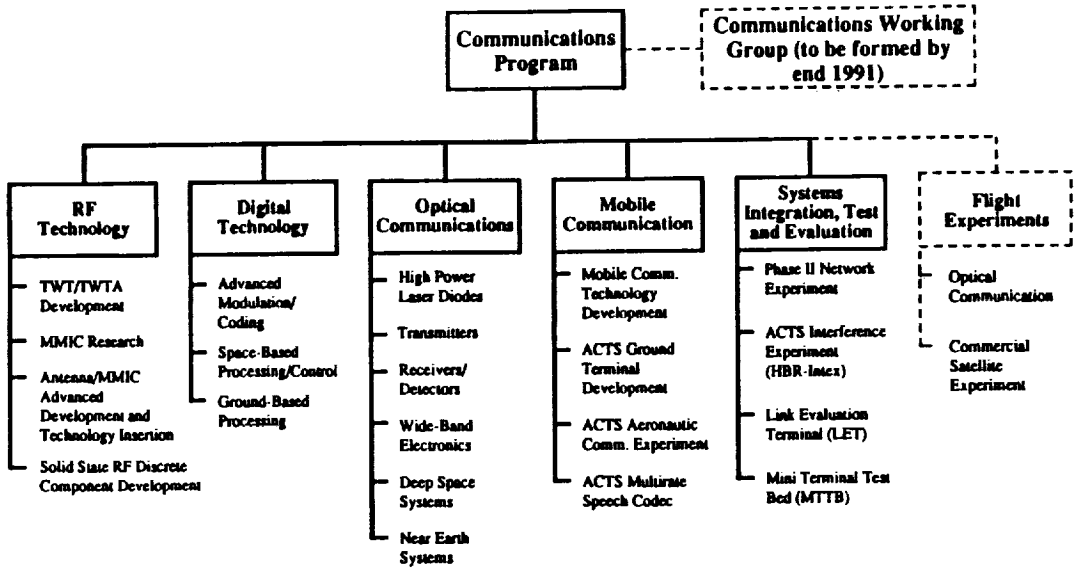
- HIGH RATE COMMUNICATION FROM 20 GHz TO 90 GHz
- MOBILE SATELLITE COMMUNICATION FOR AERONAUTIC AND PERSONAL USE
- OPTICAL COMMUNICATION FOR NEAR EARTH AND DEEP SPACE
- HIGH SPEED DIGITAL TECHNOLOGY FOR AUTONOMOUS ONBOARD PROCESSING AND COST EFFICIENT GROUND TERMINALS
- GROUND-BASED SATELLITE COMMUNICATIONS SIMULATOR AND TESTBED

RC

COMMUNICATIONS PROGRAM

OAET

WORK BREAKDOWN STRUCTURE



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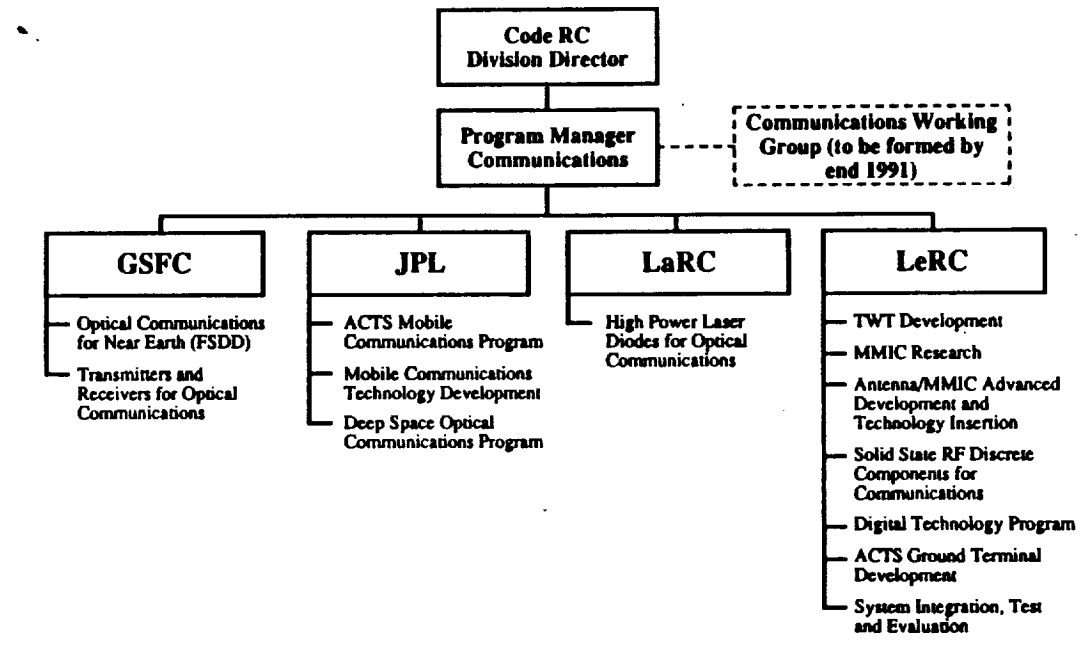
COMMUNICATIONS PROGRAM

OAET

ORGANIZATIONAL CHART



COMMUNICATIONS PROGRAM

RC

OAET

STATE OF THE ART:	Today	Goals
RF Technology		
TWT's	7-10 W output at Ka-band (32 GHz) 5 W output at 60 GHz	20-50 W - 50% eff. (Ka-band) 20 W - 40% eff. (60 GHz)
MMIC Phased Array MMIC Amplifier	21 element, 5 W, 15% P.A.E. 0.5 W Ka-band amplifier	50 elements, 180° coverage 5 W Ka-band amplifier 1 W 60 GHz amplifier
MMIC Modules	Laboratory modules available, pilot line fabrication in place, some S class modules	
Solid State Technology Components	Competitive with TWT Ku-band, ≤10 W	High eff., long lifetime (ISY)
Data Rate	200 Mbps	1 to 5 Gbps
Digital Technologies		
Digital Switching/onboard Modulation Source Coding/data Compression	300 Mbps, ACTS: 110 Mbps, order wire TV-3 Mbps, Speech-9.6 Kbps	Up to 2 Gbps TV-1 Mbps; Speech-2.4 Kbps KHz frame rate
Mobile Communication Technology		
Mobile System	Ka-band 9.6 Kbps, 22 dBi Low profile tracking antenna Mobile Personal System	L & Ka-band mobile satellite comm. Aeronautical system communication
Optical Communication		
Laser Power Transmitter and Receivers	High promise technologies demonstrated, e.g., 350 mW, 5% eff. laser. No system or flight demo.	10 Gbps, 30 Kbps at 3.5 AU
Systems Integration, Test & Evaluation		
Ground-based Satellite Comm. Simulator and Testbed	One terminal operational	Two and three terminal demonstration

COMMUNICATIONS PROGRAM

RC

OAET

Projected Needs for Future NASA Missions

Technology Challenge	Requirement	Mission
RF Technology		
8-94 GHz TWT's	Increased efficiency, high output power, high reliability, small size and weight	CRAF, Cassini, Lunar/Mars exploration, Space Station, Mars Observer, EOS, and commercial applications
MMIC's	Order of magnitude reduction in size and weight of microwave circuitry, increased reliability, multiple beam, electronically scanned antennas	Mars Rover, Lunar/interplanetary relays, EOS, intersatellite communications links, Cosmic Microwave Background Measurements
MMIC subarrays/arrays	Increased gain/data rate, increased scanning performance/communication system connectivity, enhanced reliability, and lower costs at lower size and weight.	Mission-to-Planet-Earth, Space Station , Mission-from-Planet-Earth, STS, antenna systems for commercial satcom systems and fixed and mobile earth terminals
Solid state microwave components	Smaller, lighter, more efficient, solid state devices; smaller communication systems with reduced power requirements; Ka-band solid state power amplifier	Lunar/Mars exploration; Space Station; commercial communications; Commercial very small aperture terminals
Digital Technology		
Bandwidth and power-efficient modulation and coding	Bandwidth efficiencies >1.7 bps/Hz; Power efficiency comparable to BPSK; Space-based, real-time video/data distribution	Lunar/Mars exploration; Space Station; commercial communications; Commercial very small aperture terminals
Onboard signal processing, switching, routing and autonomous network control	Increased connectivity and data rates to 800 Mbps;	Commercial communications
High speed circuits	Wideband electronics for high-speed optical and RF communication	Mars Rover, Lunar/interplanetary relays, intersatellite communications links,

COMMUNICATIONS PROGRAM

RC

OAET

Projected Needs for Future NASA Missions (Cont.)

Technology Challenge	Requirement	Mission
Optical Communications		
High power and high data rate semiconductor diode lasers	Improved communications data rate, range of communications and overall data handling capability for data communication systems	Mars Rover, Lunar/interplanetary relays, intersatellite communications links, Cosmic Microwave Background Measurements
High sensitivity, high bandwidth detectors	High capacity and data rates for intersatellite optical links; reduced power, size and weight requirements	Lunar/Mars exploration; Space Station; Mars Observer, EOS, and commercial applications
Point/track antennas	Reducing size, weight and power; eliminating risk of antenna deployment, unfurlment; eliminating issues of frequency allocation, crowding	NASA data relay system (ATDRSS) using GEO x-links.
System Integration, Test & Evaluation		
Satellite Communication System Simulator and Testbed for system experimentation	Demonstrate advanced components, subsystems and network architectures. Test and evaluate components and subsystems for NASA and industry space operations and commercial programs. Evaluate effects of atmospheric and propagation disturbances, interference, noise non-linearities, satellite motion and hardware and system imperfections on system performance.	CRAF, Cassini, Lunar/Mars exploration, Space Station, Mars Observer, EOS, ATDRSS, Lunar/interplanetary relays, intersatellite communications links, and commercial applications
Mobile Communication		
Advanced, high risk Mobile Satellite Communications (MSAT) technologies	Increased terminal data rates, spectral and power efficiency, and improved robustness in the fading channel.	Maintain U.S. preeminence in Satellite Communications Technology. Expand applications of the technology. Support advocacy of effective spectral utilization, industry development, and public safety.

COMMUNICATIONS PROGRAM

RC

OAET

Needs For Future Commercial Satellites:

- Onboard demodulation/remodulation (regeneration) for low and high rate transmissions (from 1 Kbps to 2 Gbps)
- Onboard multichannel demultiplexing and demodulation
- Stationary and hopping multiple beam transmission
- High power SSPA's for Ku and Ka-band
- High efficiency burst HPA for TDMA Earth terminals
- High efficiency Ku and Ka-band TWTA
- High reliability, long life (15 years) TWTA, MMICS, SSPA
- Steerable Ku and Ka-band flat plate antennas
- Improved channel coding and coded modulation (3-5 bits/Hz)
- Source coding and bit rate reduction (1 Mbps for TV and 2 Kbps for mobile communications)

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COMMUNICATIONS PROGRAM

OAET

ACCOMPLISHMENTS:

- Demonstrated the first Ka-band (32 GHz) TWT with 10 W output power and 35% efficiency
- Demonstrated fastest Viterbi Decoder (225 Mbps) for data integrity
- Demonstrated the first Ka-band (32 GHz) 0.75W MMIC amplifier
- Demonstrated the first Ka-band MMIC Phased Array Antenna with 7 waveguide elements
- Developed a small (< 5 Kg) optical communications breadboard transceiver
- Demonstrated phase-tracking coherent optical receiver using stabilized Nd:Yag laser that operated at 10 pW received power
- A 50 Mbps direct detection receiver has been completed; a 220 Mbps device is in fabrication (to be completed in 1991)
- Demonstrated the first L-band mobile satellite terminal on terrestrial vehicles and aircraft
- Developed and demonstrated the first satellite communications systems simulated testbed which operates at Ka-band (one terminal in operation)
- Developed a high burst rate (110 and 220 Mbps) TDMA ground terminal for operation at Ka-band in supports of ACTS (will test the uplink power control feature)
- Developed and patented a novel, highly efficient, and fade robust digital/speech modems

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COMMUNICATIONS PROGRAM

OAET

PROGRAM MILESTONES:

RF Technology
- Brassboard demonstration of a Ka-band TWTA with 20W input, 7W output - 1991
- Demonstrate a Ka-band 1W MMIC amplifier with 10 dB gain and 35% efficiency - 1992

Digital Technology
- Demonstrate 300 Mbps Information Switching Processor - 1994
- Demonstrate a 728 channel multichannel demultiplexer demodulator - 1995

Optical Communications Technology
- Demonstrate a 2W Monolithic Active Grating Master Oscillator power amplifier with 1 GHz modulation - 1993
- Demonstrate 1W 1 Gbps diode pumped Nd doped laser - 1992
- SCOPE breadboard test, 100 Kbps coherent receiver demonstration - 1991
- Systems Testing and Evaluation of Optical Communications Flight-Like Package, 650 Mbps, 200W, 250 lbs. - 1993

Mobile Satellite Communications
- ACTS Mobile Satellite Experiment using active array antenna - 1994
- ACTS Mobile Aeronautical Experiment - 1993

Systems Integration, Test and Evaluation
- Demonstrate two and three terminal network experiments - 1992

RC

COMMUNICATIONS PROGRAM

OAET

RELATED NASA PROGRAMS:

- Office of Space Operations - Code O
  ($22M in advanced system development)
  - Tracking, orbit determination and navigation
  - Spacecraft to ground communications, telemetry, and command
  - Data handling and processing
  - Network data processing and productivity
  - Station controls and system technology
  - ATDRSS*
- Office of Commercial Programs
  - Advanced Systems Studies
  - CCDS in Communication
- Office of Space Science and Applications - Code S
  - ACTS

* separate funding, not part of advanced system development funding

RC

COMMUNICATIONS PROGRAM

OAET

NON-NASA PROGRAMS:

- R&D program at SDIO
  - RF Communications - 60 GHz and terahertz communications
  - Optical Communications - Laser communications
- Naval Research Laboratory
  - HTSC component development for radar and communication systems and subsystems
- Air Force/Space Communications R&D
  - Rome Lab - Communications up to 90 GHz
  - Phillips Lab - Focal plane array signal processing
- DARPA - Submarine Laser Communications
- Martin Marietta/McDonnell Douglas/TRW/Ball Aerospace
  - Major programs in Laser communications technology

RC

COMMUNICATIONS PROGRAM

OAET

RESOURCES ($,M)

	FY91	FY92	FY93	FY94	FY95	FY96	FY97
Existing Program							
NASA and Commercial Satellites	17	20.4*	21.8	21.2	22.0	23.1	24.2
Resources Breakdown FY92 Only							
RF Comm. Technology		7.4					
Digital Comm. Technology		2.4					
Optical Communications		4.3					
ACTS Mobile Terminal		3.3					
Mobile Comm. Technology Development		0.5					
Satellite Comm. Advanced Research		2.0					

* Includes resources for HQ service support and program reserves

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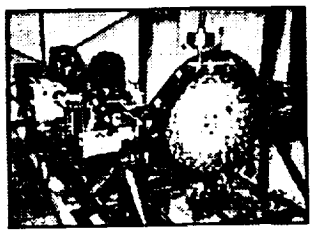
COMMUNICATIONS PROGRAM

OAET

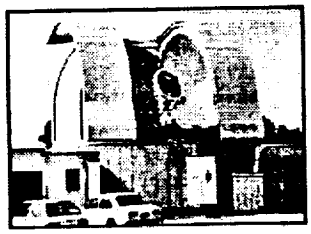
NASA COMMUNICATIONS FACILITIES

NASA COMMUNICATIONS FACILITIES

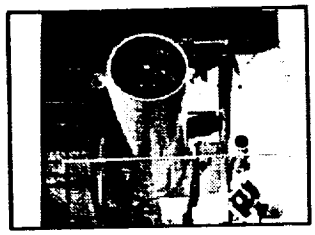
NASA GSFC Communications Facilities



Electro-Optical
I&T Cleanroom

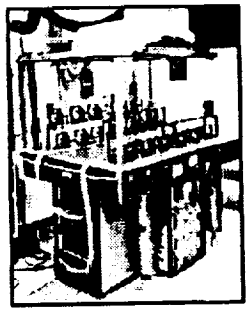


Goddard 1.2m Optical
Research Facility

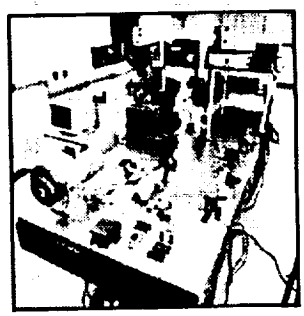


30 Inch Tracking Telescope

Ultrafast Laser
Development Lab



Semiconductor Laser Lifetest



Lasercom Testbed

GSFC Communications Facilities

Electro-Optical I&T Cleanroom - The Electro-Optical Integration and Test Cleanroom is used for the test and assembly of precision optical instruments. The photograph shows the testing of the Laser GEOdynamics Satellite (LAGEOS). The assembly and testing of the Optical Communications Flight System Demonstration and Development (FSDD) apparatus will be conducted in this facility.

Goddard Optical Research Facility - The Goddard Optical Research Facility (GORF) is an optical laser satellite tracking facility. Located five miles north of the Goddard campus, the facility features short pulse Q-switched high power three color Nd lasers, streak cameras, electronic support equipment and computers for conducting research and development of laser radar, lidar and laser communications projects. University, civilian and defense Government and industrial personnel use the GORF for cooperative research efforts. GORF has recently conducted laser ranging experiments to the LAGEOS satellite (see above).

1.2 meter Tracking Telescope - The 1.2 meter Tracking Telescope employs a coude optical system with a focal ratio of f/26.3 and an equivalent focal length of 21 meters. An indexable mirror within the pier at the coude room level permits the light bundle to be quickly redirected through any one of eight ports to eight possible experiments. The entire movable structure rides on an azimuth air bearing. Precision roller bearings are used for the elevation axis. Each axis is equipped with a directly coupled torque motor, tachometer and 22-bit digital shaft angle encoder. The system is controlled from an optical console in the computer/control room. For satellite tracking, a computer generates telescope pointing commands in real time from polynomials describing the satellite's position.

Ultrafast Laser Development Laboratory - The Ultrafast Laser Development Laboratory is one of five optical laboratories in the Goddard Photonic Branch. The efforts in this laboratory are aimed at constructing picosecond diode pumped solid state lasers for communications, laser ranging and lidar. The laboratory has an Argon-Ion pumped Ti:Sapphire laser as an alternative tunable diagnostic pump source.

Semiconductor Laser Lifetest - Goddard has constructed a semi-automated Semiconductor Laser Lifetest facility. The facility allows the simultaneous monitoring of the polarization, power, wavefront and spectral properties of 22 semiconductor lasers. The electronic drivers allow operation at 50 mA 100 MHz squarewave modulation at constant DC current. The lifetest was conducted on several leading laser vendors lasers over a three year period (1987-1990). The lifetest facility was recently placed in storage pending laser, laser driver, cleanroom and computer upgrades.

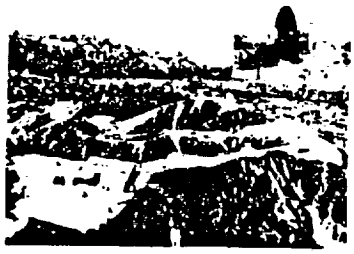
Laser Communications Testbed - Goddard is in the process of constructing a fully operational 625 Mb/s Laser Communications Testbed in an off-site clean room facility. The project, called the Optical Communications Flight System Demonstration and Development (FSDD), will provide heritage to spaceflight experiments and operations in the nineties and is expected to be completed in 1994.

GSFC

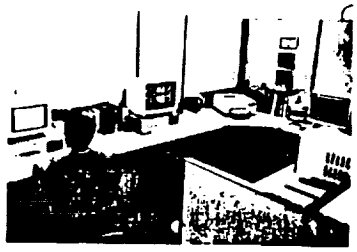
NASA

JPL

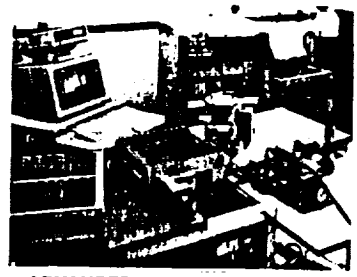
COMMUNICATIONS DEVELOPMENT FACILITIES



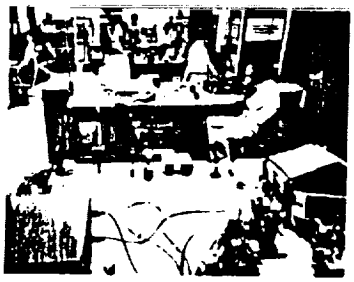
MESA ANTENNA RANGE



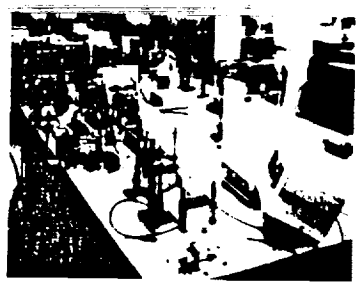
MMIC DESIGN LABORATORY



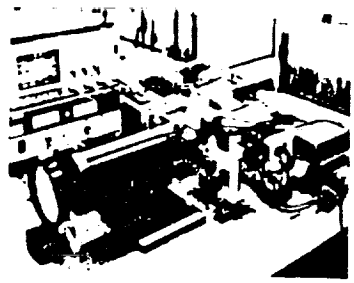
ADVANCED CRYO-ELECTRONICS LABORATORY



OPTICAL COMMUNICATIONS DEVELOPMENT LABORATORY



LASER TRANSMITTER DEVELOPMENT AREA



INTEGRATED OPTICAL COMMUNICATIONS TEST BENCH

JPL COMMUNICATIONS DEVELOPMENT FACILITIES

CLOCKWISE, FROM UPPER LEFT:

MESA ANTENNA RANGE: THIS RANGE PROVIDES ANTENNA TESTING FACILITIES FOR FLIGHT PROJECTS AND RESEARCH AND DEVELOPMENT PROGRAMS AT JPL. THE RANGE HAS 5 OUTDOOR FAR-FIELD RANGES WITH LENGTHS FROM 200 TO 3300 FT. IN ADDITION, THERE ARE TWO ANECHOIC CHAMBERS, ONE OF WHICH CONTAINS PLANE-POLAR AND CYLINDRICAL NEAR-FIELD SCANNERS. A LARGE RADIO FREQUENCY VOLTAGE BREAKDOWN CHAMBER IS ALSO AVAILABLE FOR TESTING COMPONENTS UNDER DEEP-SPACE ENVIRONMENT.

MMIC DESIGN LABORATORY: THIS IS A COMPUTER-AIDED DESIGN (CAD) FACILITY FOR DESIGN AND DEVELOPMENT OF MMIC (MONOLITHIC MICROWAVE INTEGRATED CIRCUIT) DEVICES. MMIC DEVICES DESIGNED HERE ARE FABRICATED AT A COMMERCIAL MMIC FOUNDRY AND TESTED AT JPL. THIS CAPABILITY ENABLES JPL TO UTILIZE MMIC TECHNOLOGY IN FUTURE SPACECRAFT DEVELOPMENT.

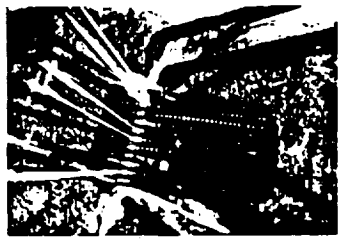
ADVANCED CRYO-ELECTRONICS LABORATORY: THIS LABORATORY HAS FACILITIES TO CHARACTERIZE MICROWAVE DEVICES AND COMPONENTS AT CRYOGENIC TEMPERATURES. PRESENTLY, NOISE AND SCATTERING PARAMETERS CAN BE MEASURED FROM 0.8 TO 40 GHZ IN THE PHYSICAL TEMPERATURE RANGE OF 300 TO 12 KELVIN. THE LABORATORY ALSO HAS THE CAPABILITY OF EVALUATING THE RF AND NOISE TEMPERATURE PERFORMANCE OF COMPONENTS AND DEVICES DOWN TO A PHYSICAL TEMPERATURE OF 1.5 KELVIN.

INTEGRATED OPTICAL COMMUNICATIONS TEST BENCH: THIS TEST FACILITY EMPLOYS BOTH REALISTIC-SIZED ELECTRO-OPTICAL SYSTEMS AND GENERAL PURPOSE ELECTRONIC AND COMPUTER SUPPORT SYSTEMS TO PERMIT THE EVALUATION OF OPTICAL COMMUNICATION TECHNOLOGIES IN AN INTEGRATED SYSTEM SETTING. SPATIAL ACQUISITION AND TRACKING HARDWARE AND ALGORITHMS ARE THE CURRENT PRIMARY FOCUS, PARTICULARLY TECHNIQUES FOR TRACKING EXTENDED SOURCE (EARTH-IMAGE) BEACONS.

LASER TRANSMITTER DEVELOPMENT AREA: THIS AREA FACILITATES THE DEVELOPMENT OF HIGHLY EFFICIENT SOLID-STATE LASER DESIGNS. SHOWN IS A PULSED, GREEN ND:YAG LASER THAT PRODUCED 340 mW OF OUTPUT POWER. DESIGNS DEVELOPED HERE ARE TRANSFERRED TO CUSTOM-DESIGNED MODULES FOR SPACE-ENVIRONMENTAL TESTING.

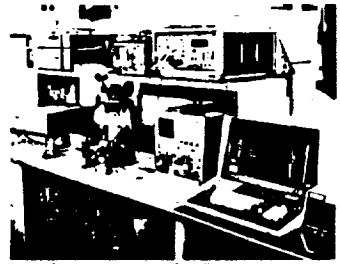
OPTICAL COMMUNICATIONS DEVELOPMENT LABORATORY: MANY OF THE BASIC DEMONSTRATIONS OF OPTICAL COMMUNICATIONS TECHNOLOGY TAKE PLACE IN THE OPTICAL COMMUNICATIONS DEVELOPMENT LABORATORY. THE LABORATORY OCCUPIES 1300 SQ FT AND HAS LIGHT-TIGHT CURTAINS WITH INDEPENDENT LIGHT CONTROLS TO PERMIT PARTITIONING THE ROOM INTO FOUR SEPARATE BAYS.

Langley Communications Program Facilities and Capabilities

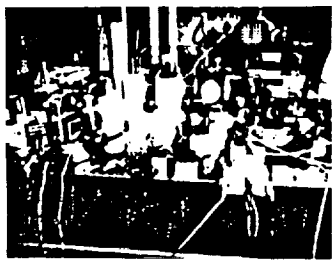


Semiconductor Laser Testing

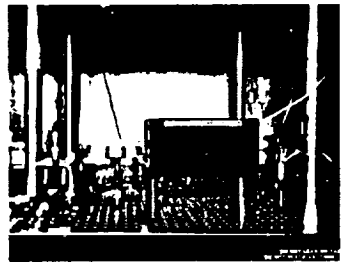
Automated Laser Evaluation System



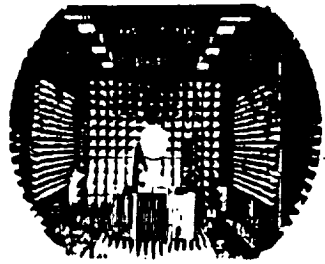
Gigahertz Transceiver Design Lab



Optical Components Development Laboratory



S C Laser Optical Characterization System



R F Antenna Design and Test Facility

Langley Research Center Communications Program and Facilities are mainly in the area of optical communications concerning the development of high power semiconductor lasers, the demonstration of these laser in-house developed optical communication transceivers and a program in RF antenna development and testing.

High power semiconductor laser testing is performed in-house at Langley Research Center in the Information Systems Division of the Information Processing Technology Branch's Photonics Laboratory. Within this laboratory exists the capability which is utilized to fully characterize the optical and electronic properties of high power lasers. In additon there is a companion capability to fabricate GigaHertz data rate optical transmitters used to determine the stability and performance of high power lasers being developed for optical communication applications.

Within the Photonics Laboratory is an Automated Laser Evaluation System which performa power-current, wavelength - current, linewidth, relative intensity noise and othere tests as a function of temperature in a programmed manner which can be set by the user of the system. Once the parameterization of the tests are entered into the computer the engineer can walk away and come back with a complete data set stored in the computer in data form for his use in report writing.

A GigaHertz Transceiver Design Laboratory exists where high speed printed circuits are designed that utilize the latest high speed GaAs integrated circuits for driving the lasers or for detecting the transmitted optical emission. A complete line of capability exists from multiplexer, driver, control and regulation functions to detection, transimpedance amplifier designs, linear amplifiers, clock recovery and demultiplexer designs have been demonstrated.

Optical Components Development Laboratory looks at various optical isolators, lens, attenuators, mirrors and mounting systems for use in optical systems for evaluating lasers and measuring their properties as well as designing systems for use in optical communication applications.

The Semiconductor Laser Characterization System is used primarily in looking at coherent communications applications where laser linewidth stability as a function modulation type, optical feedback effects and long term stability of the lasers. In concert with these tests and evaluations of linewidth stability is a measurement of the relative intensity noise of the laser which also quantifies the ability of the laser to perform in a stable manner in various modulation and optical feedback conditions.

The R. F. Antenna Design and Test Facility is used for testing candidate RF communications antenna for the AFE spacecraft. A candidate antenna is shown in the Low Frequency Antenna Test Chamber located in AMRB of the GCND at Langley.

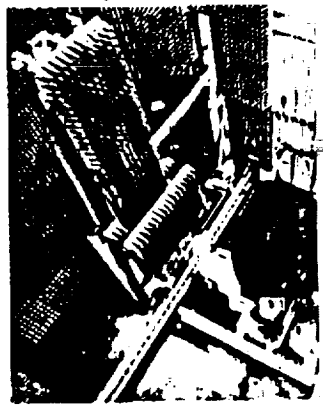
National Aeronautics and Space Administration
Lewis Research Center

SPACE ELECTRONICS DIVISION NASA

Lewis Space Communications Facilities

Systems integration, and evaluation test bed

22' x 22' Near field planar scanner



TWT modification for multi-stage depressed collector studies

ASIC design lab

Solid state materials characterization lab

CD-90-55360

AEROSPACE TECHNOLOGY DIRECTORATE

SPACE ELECTRONICS DIVISION

NASA Lewis Research Center

Lewis Space Communications Facilities

Lewis has numerous specialized facilities and equipment for research related to space communications. The total capability occupies approximately 25000 square feet and has a replacement value of about $21 million. Several of these facilities are shown in the following charts. The broad diversity of these facilities is illustrated by the examples on the accompanying chart.

- The Systems Integration, Test and Evaluation Lab is a unique, end-to-end space communication link simulator. The facility includes the satellite portion of a space communications channel, as well as several ground terminals, combined into a communications network under computer control to present an accurate model of a satellite communications system. The test facility's flexibility allows the performance of system-level experiments, evaluation of advanced system design concepts, component performance, hardware and software, and networking and control technology.
- Lewis has six laboratories for developing advanced digital hardware and software for space communications applications: CAD and ASIC Design Lab, Artificial Intelligence and Expert Systems Lab, Neural Networks Lab, Digital Signal Processing Lab, Mass Data Storage Lab, and the Digital Development Lab. The ASIC design lab shown in the photo is used for schematic capture and simulation of digital logic circuits for implementation in wire-wrap or multi-layer printed circuit boards with discrete chips, programmable logic devices, semi-custom gate arrays, and full custom VLSI circuits.
- The 22' x 22' near-field planar scanner (illustrated) is one of four state-of-the-art facilities making up the LeRC Microwave Systems Laboratory (MSL) in Building 7. The MSL supports experimental investigations in the Antenna Technology Program ranging from MMIC device characterization and printed circuit (patch) radiators studies through sub-array, array/array feed and large reflector system level testing. The other facilities include the recently Automated Far-field Lab, the RF Characterization Lab (packaging and characterization of MMIC and SLIC devices) and the Optics-in-Arrays (OIA) Lab.
- The TWT Efficiency Enhancement Laboratory was designed and built by LeRC personnel, and provides NASA with a unique measurement capability that has enabled the agency to achieve a leading role in this field. The computer-aided measurement systems permit comparative determinations of tube parameters and efficiency optimization over a wide range of operating conditions.
- Numerous solid state research facilities include laser ablation facilities for the deposition of superconductors and other electronic materials, Test and Evaluation Facilities for MMIC Circuitry, Cryogenic Microwave Test Facilities, and a Solid State Materials Characterization Lab (picture). Dr. J. Pouch carried out a measurement using the surface analysis unit, which can perform Auger, ESCA, and SIMS measurements. Other branch facilities permit conventional Hall Effect measurements at temperatures from 1K to 500K, optically modulated Hall effect measurements, and magnetization measurements to a few degrees K.

RC

COMMUNICATIONS PROGRAM

OAET

NEW AREAS FOR AUGMENTATION REQUESTED:

- **HIGH RATE COMMUNICATIONS - PROGRAM START - 1993**
- **OPTICAL COMMUNICATIONS FLIGHT EXPERIMENT PROGRAM START - 1994**
- **COMMERCIAL COMMUNICATIONS SATELLITES TECHNOLOGY PROGRAM START - 1993**
- **COMMERCIAL COMMUNICATIONS EXPERIMENTS PROGRAM START - 1994**

INTEGRATED TECHNOLOGY PLAN

OPERATIONS TECHNOLOGY PROGRAM

OAET

INFORMATION & COMMUNICATIONS TECHNOLOGY

JUSTIFICATION

High Rate Communications Are Needed To Enable Effective Utilization Of Advanced Science Sensors.

- Lower mass, power and volume communications systems are needed to increase mission science payload
- High rate communications are needed to enable:
  - Advanced deep space missions (Solar probe, MRSR, Neptune and Uranus Orbiter
  - Advanced Earth-orbiting missions (EOS-B, SIRTF, Advanced TDRSS)
  - Space exploration missions (lunar surface missions, manned lunar and Mars missions)

OBJECTIVES

Technology development is required to support advanced deep-space and near-Earth missions requiring transmission of high data rates (1) between planetary surfaces and spacecraft and (2) between spacecraft.

Technology areas of interest are as follows:
- Optical Communications
- RF Communications
- Digital Communications
- Communications Systems Integration

HIGH RATE COMMUNICATIONS

MILESTONES

- 1994 – Demonstrate an electronic power conditioner for 60 GHz TWT
- 1995 – Demonstrate a 60-watt traveling wave tube amplifier breadboard at 32 GHz
- 1995 – Demonstrate breadboard coherent optical transponder
- 1996 – Demonstrate a multibeam MMIC sub-array at 20 GHz
- 1997 – Demonstrate an ultra-fast laser diode module for optical communications
- 1998 –Demonstrate a phase-locked two-dimensional diode array

RESOURCES

Budget ($,M)	1992	1993	1994	1995	1996	1997
CURRENT	5.0	5.2	5.4	5.6	5.8	6.0
'93 STRATEGIC PLAN	----	6	7.9	12	15	20
'93 3 X BUDGET PLAN	----	5.3	7.1	9.8	12.5	18.0

- **Basis for Estimate**
  Augmentation needed to provide high rate communications systems needed to satisfy future mission requirements

INTEGRATED TECHNOLOGY PLAN

OPERATIONS TECHNOLOGY PROGRAM

OAET

INFORMATION & COMMUNICATIONS TECHNOLOGY

JUSTIFICATION

- **Mission Needs**
  - Autonomous acquisition, tracking and beam pointing
  - Gbps communications link capability for relay of data from instruments such as synthetic aperture radars
  - Enhanced data relay in the near-Earth environment
- **Missions**
  - ATDRSS (GEO inter-satellite)
  - STS (LEO inter-satellite)
  - GEO-to-ground
  - LEO-to-ground

OBJECTIVES

- **Programmatic**
  Develop and demonstrate high data rate (1 Gbps) communications links for both intersatellite and space-to-ground applications
- **Technical**
  - Reliable one-watt lasers
  - Micro-radian pointing accuracy
  - Pulse-position modulation pointing
  - Sensitive wideband receivers

OPTICAL COMMUNICATIONS FLIGHT EXPERIMENTS

MILESTONES

- 1994 – GEO terminal system level CDR
- 1995 – GEO terminal subsystem integration
- 1996 – LEO terminal system level CDR
- 1997 – LEO terminal subsystem integration
- 1997 – GEO terminal launch
- 1998 – GEO terminal operational readiness
- 1999 – LEO terminal launch readiness review

RESOURCES

Budget ($,M)	1992	1993	1994	1995	1996	1997
CURRENT	2.1	2.2	2.3	2.3	----	----
'93 STRTEGIC PLAN	—	6.0	15.5	20	22	19
'93 3 X BUDGETPLAN	-TBD START YR.-					

- **Basis for Estimate**
  Augmentation needed to validate the performance of needed technology in an operational space environment

INTEGRATED TECHNOLOGY PLAN

OPERATIONS TECHNOLOGY PROGRAM

OAET

INFORMATION & COMMUNICATIONS TECHNOLOGY

JUSTIFICATION

- Service needs
  All areas of commercial communications satellite services can greatly benefit from new technologies which increase the utilization of available frequencies and bandwidth and more efficiently transform satellite power into RF radiated power with higher information content. By exploiting the unique vantage point of space, new global communications services are possible, extending to the personal level.

OBJECTIVES

- **Programmatic**
  Develop new and enabling satellite and ground technologies to the level needed to remove the risk to the industry of introducing new communications services which will benefit mankind.
- **Technical**
  - Active phased array satellite antennas
  - Bandwidth and power efficient modem, coding, and onboard routing and processing systems

SATELLITE COMMUNICATIONS TECHNOLOGY

MILESTONES

- 1995 – Innovative new mobile and small fixed terminals developed.
  System level MMIC's developed.
- 1997 – Active phased array antenna developed using digital beam forming; breadboard optical processor / router developed
- 1998 – Advanced mobile terminal components developed
- 1999 – Proof-of-concept optical beam forming network completed
- 2000 – Complete development of advanced onboard communications processing and routing subsystem

RESOURCES

Budget ($,M)	1992	1993	1994	1995	1996	1997
CURRENT	10.8	12.5	13.1	13.8	14.5	15.2
'93 STRATEGIC PLAN	—	8.8	9.8	11.7	12.1	12.6
'93 3 X BUDGET PLAN		3.9	6.0	9.0	9.4	13.0

- **Basis for Estimate**
  Augmentation is needed to accelerate current technology development work and begin new enabling technologies in response to growing service needs and opportunities in the presence of international communications competition and limited natural resources (orbit space and frequency spectrum).

INTEGRATED TECHNOLOGY PLAN

OPERATIONS TECHNOLOGY PROGRAM

OAET

INFORMATION & COMMUNICATIONS TECHNOLOGY

JUSTIFICATION

- Service needs
  All areas of commercial communications satellite services can greatly benefit from new technologies which increase the utilization of available frequencies and bandwidth and more efficiently transform satellite power into RF radiated power with higher information content. By exploiting the unique vantage point of space, new global communications services are possible, extending to the personal level.

OBJECTIVES

- **Programmatic**
  Develop and implement relevant space communications systems, both satellite and ground, which contribute to improved services for the public benefit, and promote the development of selected technologies to the point of commercial acceptance.
- **Technical**
  - Active phased array satellite antennas
  - Bandwidth and power efficient modem, coding, and onboard routing and processing systems
  - Mobile and fixed service communications terminal technologies.

SATELLITE COMMUNICATIONS EXPERIMENTS

MILESTONES

- 1995 – Test and validate land mobile technology
- 1996 – Test and validate aero/maritime mobile technology
- 1997 –Test and validate high power, high efficiency TWTA Test and validate direct broadcast audio receiver
- 1998 – Flight validate active phased array antenna
- 1999 – Test and validate onboard digital processor/router
- 2000 – Test and validate personal communications technology

RESOURCES

Budget ($,M)	1993	1994	1995	1996	1997
CURRENT	—	—	—	—	—
'93 STRATEGIC PLAN	5.4	12.7	21.7	27.4	29.5
'93 3 X BUDGET PLAN	- TBD START YR.-				

- **Basis for Estimate**
  Augmentation is needed to extend the development of new communications satellite technologies to the level of readiness for validation at the system level and to perform the validation on the ground or as a flight experiment.

RC

COMMUNICATIONS PROGRAM

OAET

PROGRAM MILESTONES WITH AUGMENTATION

RF Technology

- Brassboard demonstration of a Ka-band TWTA with 20W input, 7W output - 1991
- Demonstrate a Ka-band 1W MMIC amplifier with 10 dB gain and 35% efficiency - 1992
- *Demonstrate an electronic power conditiioner for 60 GHz TWT - 1994*
- *Demonstrate a multibeam MMIC subarray at 20 GHz - 1996*
- *Test and validate direct broadcast audio receiver - 1997*

Digital Technology

- Demonstrate 300 Mbps Information Switching Processor - 1994
- Demonstrate a 728 channel multichannel demultiplexer demodulator - 1995
- *Test and validate onboard digital router - 1999*
- *Complete development of advanced onboard communications processing and routing system - 2000*

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COMMUNICATIONS PROGRAM

OAET

PROGRAM MILESTONES WITH AUGMENTATION Cont.

Optical Communications Technology

- Demonstrate a 2W Monolithic Active Grating Master Oscillator power amplifier with 1 GHz modulation - 1993
- Demonstrate 1W 1 Gbps diode pumped Nd doped laser - 1992
- SCOPE breadboard test, 100 Kbps coherent receiver demonstration - 1991
- Systems Testing and Evaluation of Optical Communications Flight-Like Package, 650 Mbps, 200W, 250 lbs. - 1993
- *Demonstrate breadboard coherent optical transponder - 1995*
- *Demonstrate an ultra-fast laser diode module - 1997*
- *GEO terminal launch - 1997*

Mobile Satellite Communications

- ACTS Mobile Satellite Experiment using active array antenna - 1994
- ACTS Mobile Aeronautical Experiment - 1993
- *Innovative new mobile and small fixed terminals developed - 1995*
- *Active phase array antenna developed using digital beam forming - 1997*

Systems Integration, Test and Evaluation

- Demonstrate two and three terminal network experiments - 1992
- *GEO terminal subsystem integration - 1995*

RC

COMMUNICATIONS PROGRAM

OAET

RESOURCES ($,M)	FY91	FY92	FY93	FY94	FY95	FY96	FY97
Existing Program							
NASA and Commercial Satellites	17	20.4	21.8	21.2	22.0	23.1	24.2
Augmentation Requested							
'93 STRATEGIC PLAN 6.0 ('93 3 X BUDGET PLAN) (5.3)							
High Rate Communications			6.0 (5.3)	7.9 (7.1)	12.0 (9.8)	15.0 (12.5)	20.0 (18)
Optical Comm. Flight Experiment			6.0 (*)	15.5 (*)	20.0 (*)	22.0 (*)	19.0 (*)
Commercial Satellite Comm. Technology			8.8 (3.9)	9.8 (6.0)	11.7 (9.0)	12.1 (9.4)	12.6 (13.0)
Commercial Satellite Comm. Flight Experiment			5.4 (*)	12.7 (*)	21.7 (*)	27.4 (*)	29.5 (*)

* TBD START YEAR IN 3 X BUDGET PLAN

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COMMUNICATIONS PROGRAM

OAET

SUMMARY:

- THE COMMUNICATIONS RESEARCH AND DEVELOPMENT PROGRAM HAS HELPED CREATE THE CURRENT COMMERCIAL CAPABILITIES AND SATISFY THE NEEDS OF THE CIVIL SPACE PROGRAM
- CURRENT U. S. LEAD IN SATELLITE COMMUNICATIONS IS THREATENED BY VIGOROUS FOREIGN INVESTMENT IN SATELLITE COMMUNICATION TECHNOLOGY
- THE LIST OF NEEDS WHICH THE CIVIL SPACE TECHNOLOGY MUST RESPOND TO FAR EXCEEDS THE PRESENT TECHNOLOGY PROGRAM
- VIGOROUS INVESTMENT IS ESSENTIAL TO SATISFY U. S. NEEDS IN FUTURE COMMUNICATIONS TECHNOLOGY

APPENDIX

Additional Technical Information on Program Elements

RC COMMUNICATIONS PROGRAM OAET

RF Communications Technology

RC

ELECTRON BEAM TECHNOLOGY

OAET

R&T SCOPE

Develop high efficiency microwave Traveling Wave Tube (TWT) technology for space communications in the frequency range of 8 GHz to 94 GHz

PAYOFFS

High frequency mm wave TWT's with increased efficiency, high output power, and high reliability with small size and weight. Order of magnitude increase in deep space data rate. High DC to RF efficiency. Ability to use uncrowded portion of the RF spectrum. Relatively low risk technology.

BENEFITS

Deep space exploration and science missions: CRAF, Cassini, Lunar/Mars exploration, Space Station, Mars Observer, EOS, and commercial applications

TECHNICAL CHALLENGE

- 20 year lifetime with high reliability
- High (>50%) efficiency over wide power range at Ka band
- Improving electron beam transmission
- Reducing cathode heater power
- Multistage collectors
- Reduction in mass and volume
- Improved reliability of high voltage power supplies

RC

ELECTRON BEAM TECHNOLOGY

OAET

APPROVED BUDGET	FY91	FY92	FY93	FY94	FY95
LeRC (K$)	2084	2025	2150	2200	2250

MAJOR MILESTONES

FY 1991	Preliminary demonstration of high efficiency 7 W, 32 GHz TWTA
FY 1992	Delivery of engineering model of 10 W, 38% efficient, 32 GHz TWTA for Cassini
FY 1993	Demonstration at CW operation of 40% efficient, 75 W, 60 GHz TWT
FY 1994	Completion of design of a high power, high efficiency 32 GHz TWT
FY 1995	High efficiency 60 W, 32 GHz TWT demonstration

AGENCY THRUST Primary: Science/Operations
Secondary: Exploration

CENTER LeRC **MISSION** CRAF/Cassini, Mars Rover, Lunar/Mars exploration; EOS

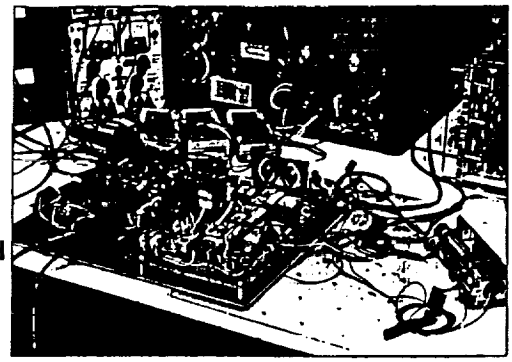
ADEQUACY OF RESOURCES

Internationally recognized researchers with unique computational and laboratory facilities; good financial support

CURRENT STATUS Technology readiness level: 4/5

ACCOMPLISHMENTS

- WORLD CLASS TWT EFFICIENCY ENHANCEMENT PROGRAM
- APPLICATION TO MARS OBSERVER X-BAND COMMUNICATIONS LINK
- 7 - 10 WATTS OUTPUT 32 GHZ TWTA WITH 20 WATTS INPUT



PROGRAM PLAN FOR CASSINI

- JOINT EFFORT WITH JPL
- 35% TWTA EFFICIENCY DOUBLES SOA
- LERC DESIGNED COLLECTOR AND SLOW WAVE CIRCUIT

IMPACT

- ENABLES EXPLOITATION OF 32 GHZ BAND FOR DEEP SPACE
- TRIPLES DATA RATE FOR CASSINI; PERMITS TRANSMISSION TO EARTH OF ALL DATA FROM MISSION

CD-91-55392

AERONAUTICS TECHNOLOGY DIRECTORATE
HIGH-EFFICIENCY TRAVELING WAVE TUBE AMPLIFIERS FOR DEEP SPACE COMMUNICATIONS
NASA Lewis Research Center

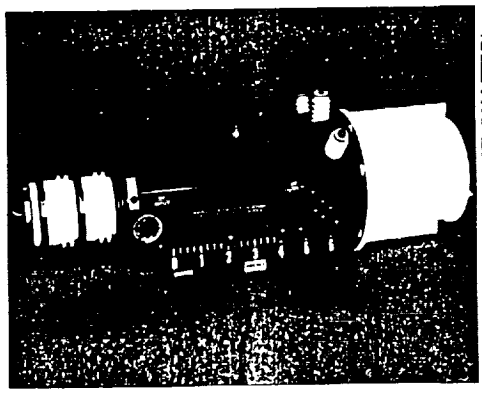
Ongoing programs at LeRC continue to provide the technologies needed for high-efficiency millimeter wave traveling wave tube amplifiers (TWTA's) for planned NASA deep space missions.

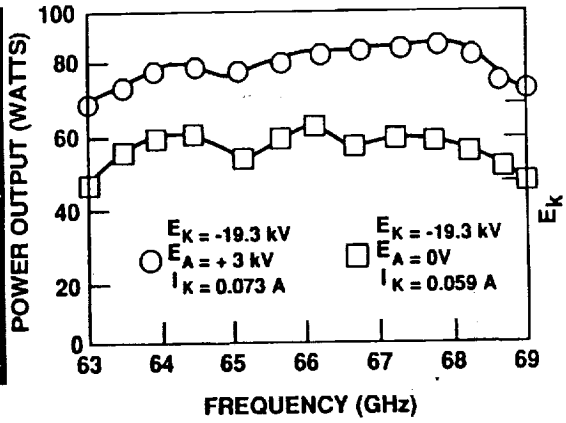
A current objective of this effort is to develop, in a contractual and cooperative effort with Hughes Aircraft Co., a very high-efficiency, high data-rate TWTA operating in Ka-band (32 GHz) for the Cassini Mission to Saturn planned for launch in 1995. The required RF power output of the tube (TWT) is 7 watts, while the DC input power to the electronic power conditioner (EPC) cannot exceed 20 watts. Achieving this performance goal will essentially double the efficiency of Ka-band TWTA's presently available at this power level. In order to accomplish this significant increase in efficiency, several LeRC-developed technologies involving computer-aided design and experimental development efforts are incorporated into the TWT. These advances include improving the interaction between the electron beam and the electromagnetic wave as well as maximizing the recovery of energy in the spent electron beam.

An advanced helix interaction section with a LeRC-designed dynamic velocity taper (DVT), is a feature of the TWT. This "tapering" results in better synchronization between the circuit wave and electron bunches than can be realized with a constant helix pitch. Further, the design of a high-efficiency multistage depressed collector (MDC) is also contributed by LeRC. In addition, during the fabrication process, the MDC electrode surfaces will be treated at LeRC using an in-house-developed process to suppress secondary electron emission.

The program will conclude with the delivery of four fully-functional Engineering Model TWT's along with one Breadboard Model EPC. Coordination with JPL has produced packaging and testing requirements for the hardware delivered from this research and development program to be a suitable immediate predecessor for the development of a flight model TWTA for the Cassini Mission.

- DEMONSTRATED PULSED PERFORMANCE 59 TO 64 GHZ BAND 75/30 WATTS, 40% EFFICIENCY
- ENABLES MULTI-GBPS RATE mm WAVE LINKS
- EPC DEVELOPMENT PROGRAM IN PROGRESS BY AIR FORCE WITH NASA CONSULTATION





CD-91-55391

LeRC is also developing technology needed for the application of 60 GHz TWTs for multi-gigabit/second intersatellite communication links. The TWTs being developed under contract by Hughes Aircraft Co. employ a coupled cavity slow-wave structure with a two step velocity taper and a LeRC designed isotropic graphite MDC.

The goal of the contract is the fabrication of TWTs capable of producing 75 Watts of RF output power over a frequency band of 59 to 64 GHz with an overall efficiency of 40% with a coupled cavity TWT. The major technical challenges are associated with having a large bandwidth and a high efficiency. Testing of the first of two TWT's has verified the basic circuit design and collector design. Saturated output power of 75 W was achieved over 4 GHz of bandwidth. Using the 4-stage graphite collector, a depressed collector efficiency of 93.9% was estimated from pulsed data, in good agreement with the computer prediction of 94.3%. This tube has two limitations that minimize the value of further processing. There are large gain variations due to a high mismatch in the output section, 30 to 50%. The output match degraded due to difficulty repairing a vacuum leak. Also, the beam focusing could not be improved beyond 90%, which made CW operation impossible. The overall TWT efficiency measured was only 32%, well below the design goal of 40%, due to the excessive electron beam interception. Had the design value of 2% beam interception been achieved, the overall TWT efficiency would have been above 40%.

Based on the test results of the first TWT, Hughes plans to make no modifications to the design of the second TWT except the previously planned alternate collector design. Though there is concern over the cause of poor focusing, there is not enough data to support a gun design change at this time.

RC

MMIC RESEARCH

OAET

R&T SCOPE

Research and development of MMIC technology for NASA missions and commercial applications. Activities address frequencies from Ku-band to W-band. Power output goals are on the order of hundreds of milliwatts. Achievable power-added efficiencies are near 30%, and noise figures .5 dB at 30 GHz to 3 dB at 90 GHz.

PAYOFFS

Order of magnitude reduction in size and weight of microwave circuitry. Increased reliability due to reduced parts count and interconnections. Enabling for multiple beam, electronically scanned antennas, thereby eliminating the need for mechanical steering of such antennas. Ka-band yields higher gain, permitting either reduced antenna size, or reduced transmitter power.

BENEFITS

Beneficial to missions utilizing high gain, highly directive antennas. Examples include Mars Rover, Lunar/interplanetary relays, large radiometers such as on EOS, intersatellite communications links, and space physics experiments such as cosmic microwave background measurements.

TECHNICAL CHALLENGE

- Improved performance (efficiency, gain, noise figure)
- Development of more effective design techniques for Ka-band and higher frequencies
- Transition of technology to system/subsystem demonstrations

RC

MMIC RESEARCH

OAET

APPRO[illegible] BUDGET	FY91	FY92	FY93	FY94	FY95
LeRC (K$)	2084	2025	2175	2200	2250

MAJOR MILESTONES

FY 1992	V-band, 250 mW MMIC amplifier
FY 1992	Ka-band, 250 mW MMIC amplifier, 15 dB gain, 50% efficiency
FY 1993	Ka-band, 1 W MMIC amplifier, 10 dB gain, 35% efficiency
FY 1994	W-band monolithic low noise receiver with 3 dB NF
FY 1995	Demonstration of HBT-based MMIC incorporating digital and RF functions

AGENCY THRUST Primary: Operations
Secondary: Science

CENTER LeRC **MISSION** Mission to Planet Earth
Lunar/Mars exploration
Commercial Applications

ADEQUACY OF RESOURCES

World class researchers, research results of excellent technical quality, funding sufficient only for level 4 development

CURRENT STATUS Current technology readiness level: 3/4 for 32 GHz
2/3 for higher frequencies

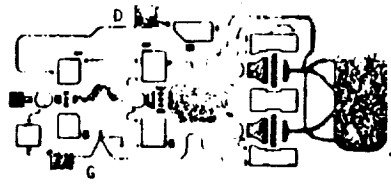
SPACE ELECTRONICS DIVISION

NASA Lewis Research Center

Ka-BAND MMIC POWER AMPLIFIER

GaAs/AlGaAs	$2x10^{18}$	450 Å
[redacted]		
$In_{0.22}Ga_{0.78}As$	$2x10^{18}$	100 Å
GaAs	$2x10^{18}$	75 Å
$In_{0.22}Ga_{0.78}As$	$2x10^{18}$	80 Å
GaAs	$2x10^{18}$	50 Å
GaAs	Undoped	1μm

Pseudomorphic double HEMT with doped channels - device structure



32 GHz 3-stage MMIC power amplifier (2.6mm x 1.2mm)

Ka-Band MMIC amplifier performance

Stages	Gate widths (μm)	Output power (mwatt)	Gain (dB)	Efficiency (%)	Frequency (GHz)
3	50-100-250	190	23	30	31
3	100-300-800	390	16	25	29
1	100	63	6.5	40	31
1	800	710	4.2	25	31

CD-90-48068

Highlights

- Record performances achieved in efficiency, gain, and power
- First 3-stage MMIC's at Ka-Band using pseudomorphic HEMT material
- Twenty matched MMIC amplifiers supplied to JPL for one-dimensional phased array demonstration
- Follow-on contract by JPL with TI for seventy MMIC amplifiers for two-dimensional Ka-Band phased array
- Forty five high performance Ka-Band MMIC's delivered to LeRC

AEROSPACE TECHNOLOGY DIRECTORATE

Ka-BAND MMIC POWER AMPLIFIER DEVELOPMENT

NASA Lewis Research Center

The objective of this program is to demonstrate the feasibility of monolithic Ka-band amplifiers for space applications. Specific goals are to produce a monolithic 3-stage amplifier with at least 250 mW power output and greater than 25% power-added efficiency. Following fabrication of initial monolithic modules, a major goal is to demonstrate their performance in a subsystem/breadboard environment. This last activity will be carried out in collaboration with one of the system technology organizations in the agency.

The most significant technological challenge is the combined power and efficiency goal. In order to achieve this performance, the contractor has utilized an innovative double heterojunction pseudomorphic structure. Such a structure features two active channels of InGaAs with GaAs buffer layers on a GaAs substrate. The InGaAs layers channels contain approximately 22% In, resulting in a moderate lattice mismatch which has been shown to be stable at the thicknesses involved here, and providing better charge containment within the active channel, as well as better mobility and saturation velocity.

The contractor, Texas Instruments, has tested various materials structures (channel thickness, doping levels), device geometries, and amplifier designs to arrive at a near optimized version of a linear amplifier. Major achievements included the development of individual field effect transistors (FETs) with the required efficiency and power handling capability, as well as the ability to simulate the performance of the full multistage circuit. The modeling becomes particularly critical for power amplifiers, where devices are being operated in a slightly nonlinear mode. A major achievement of the program has been the development of nonlinear models which accurately describe device performance under these conditions and thereby permit design of interstage matching networks which are critical to the performance of the multistage chips.

To date, the contractor has achieved record performance of over 700 mW at 25% efficiency in a 1-stage amplifier, 390 mW of power at 25% efficiency in a 3-stage module, and 190 mW of power with 23 dB of gain and 30% efficiency in a smaller 3-stage chip.

In the course of the contract, close liaison with JPL has been maintained and amplifiers were supplied for test in a breadboard array antenna at JPL. In a related procurement, JPL has purchased seventy amplifiers for further development of a two-dimensional array. Additional chips have been supplied to the antenna development programs at LeRC for use in array demonstrations with potential for use in ACTS experiments.

In ongoing work, the contractor is revising the basic FET design. He is attempting to develop an insulated gate device which will permit greater power-handling capability. In addition, a revised amplifier design will operate as a Class B module, thereby significantly increasing module efficiency. Present program goals call for modules with 250 mW of power with 50% efficiency and 1 watt of output power with 35% power-added efficiency.

Technical Contact: Dr. E. Haugland, LeRC (216) 433-3516

ANTENNA/MMIC ADVANCED DEVELOPMENT AND INSERTION TECHNOLOGY

RC OAET

R&T SCOPE

Development of advanced Ka-band MMIC and system level integrated circuit (SLIC) devices. Insertion technology development leading to MMIC subarrays/arrays for commercial and NASA missions

PAYOFFS

Ka-band arrays/array feeds offer potential for: increased gain/data rate, increased scanning performance/communication system connectivity, enhanced reliability, and lower costs at lower size and weight.

BENEFITS

Antenna systems for commercial satcom systems and fixed and mobile earth terminals, enabling antenna technology for Mission-from-planet-earth, radiometers/radars for mission-to-planet-earth, and high data rate communication systems for STS and space station applications

TECHNICAL CHALLENGE

- Bridge gap between lab environment, proof-of-feasibility MMIC devices and large, active sub-arrays/arrays ultimately qualifiable for space applications by:
  - System-specific advanced MMIC and system level IC (SLIC) development for Ka-band
  - Insertion technology development (device packaging; optical fiber links for device control and RF data distribution within array ("optics-in-arrays"); efficient printed circuit radiators and device-element coupling techniques)
- Develop devices and array architectures/configurations for multiple beam arrays

ANTENNA/MMIC ADVANCED DEVELOPMENT AND INSERTION TECHNOLOGY

RC OAET

APPROVED BUDGET	FY91	FY92	FY93	FY94	FY95
LeRC (K$)	1900	2000	2050	2100	2150

MAJOR MILESTONES

FY 1992	Demonstration of optically controlled 1 x 4 Ka-band MMIC subarray Demonstration of POC 4 x 4 30 GHz active MMIC array (Texas inst.) Demonstration of optically fed Ka-band 2 x 2 MMIC subarray
FY 1993	Active MMIC arrays demonstrated in ACTS aeronautical experiment: 32 element, 30 GHz transmit array (Texas inst.); 16 element (GE) and 23 element (Boeing) 20 GHz receive arrays
FY 1994	Complete development of 1st Ka-band system level IC (SLIC) phase shifter
FY 1995	Demonstrate 20 GHz MMIC multiple (4 beams) scanning beam 2 x 2 subarray module

AGENCY THRUST Primary: Operations; Secondary: Science

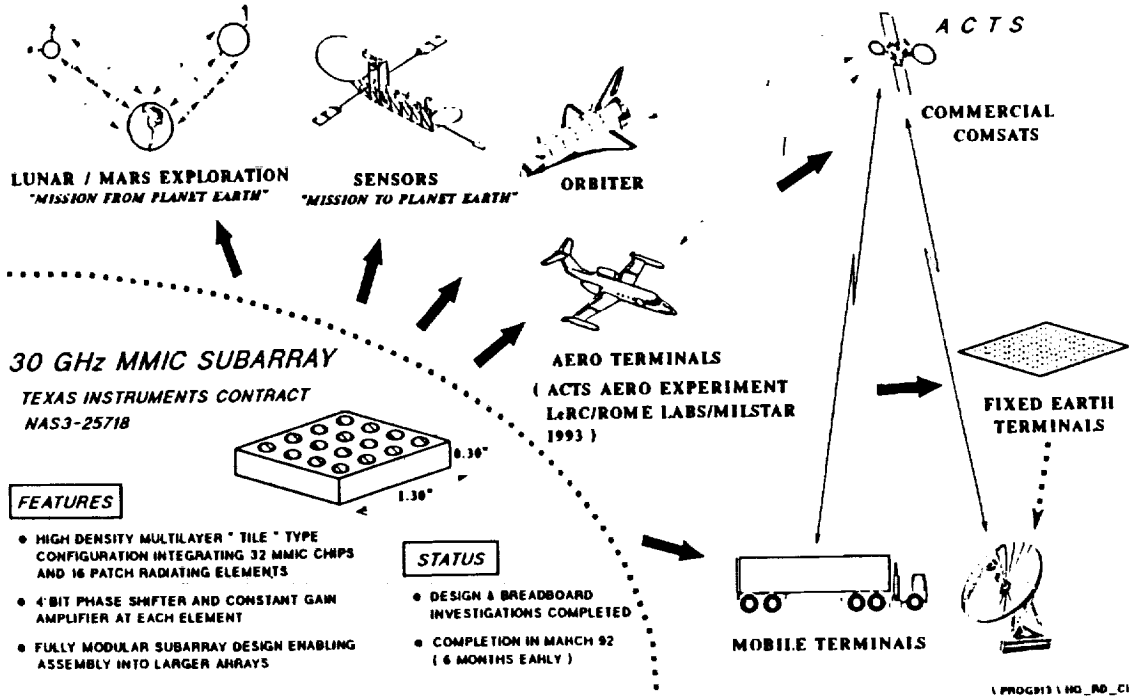
CENTER LeRC **MISSION** Commercial communications, Mission-from-planet-earth, Mission-to-planet-earth/EOS, STS and Space Station communications systems

ADEQUACY OF RESOURCES

Strong, experienced staff with excellent skill mix, outstanding ties with MMIC development community, outstanding laboratory and computational facilities, sufficient funding for focused R&D at proof-of-feasibility/concept level, but insufficient for flight qualification/experiments

CURRENT STATUS Technology readiness level: 3-4

30 GHz MMIC SUBARRAY APPLICATIONS



AERONAUTICS TECHNOLOGY DIRECTORATE
Ka-BAND MMIC INSERTION TECHNOLOGY
30 GHz MMIC SUBARRAY APPLICATIONS
NASA Lewis Research Center

Ka-band MMIC arrays have long been considered as having high potential for increased communications systems capability in terms of scan performance, data rate and connectivity at reduced size, weight and power consumption. Increased reliability (via graceful degradation) and lower cost have also been projected.

The 16-element 4 x 4 30 GHz MMIC subarray presently being developed under Texas Instruments contract NAS3-25718 is one of the most ambitious MMIC insertion programs yet attempted. The array features a high density, multilayer "tile" configuration integrating thirty-two 30 GHz chips. The radiating elements are cavity backed, aperture coupled microstrip patches. Beam steering and distributed power amplification is provided by a 4-bit phase shifter and a constant gain amplifier at each radiating element. The power amplifier is a direct descendant of an earlier LeRC sponsored TI MMIC amplifier development contract.

Excellent progress has been made on this contract, initiated in March 1990, with all key component and breadboard testing successfully completed. A final design review is scheduled at LeRC in June. Contract completion is now scheduled for March 1992, six months earlier than originally planned.

This 30 GHz transmitting subarray is one of the keys to the ACTS Aero Experiment now jointly being planned by the Space Electronics Division and the ACTS Project Office. This experiment will demonstrate a duplex voice link from a Learjet aircraft platform via ACTS to an earth terminal. The 20 GHz receive arrays will be provided via "add-on" tasks to existing Rome Labs/Milstar MMIC phased array development contracts (dual award) to GE and Boeing. The resources for these arrays are being provided jointly by the ACTS Project Office and the Milstar Program Office. Automatic tracking within the limited scan range of the arrays will be provided by an open loop tracking system tying the aircraft inertial navigation unit to the arrays beam steering computer.

The successful conclusion of the TI contract will be a significant milestone in the insertion of MMIC devices in fully modular tile-type subarrays. In addition to aircraft terminal communication systems such as demonstrated in the ACTS Aero Experiment, Ka-Band subarrays of this type will enable high data rate links in commercial communication satellite systems; fixed and mobile comsat earth terminals; NASA lunar and Mars exploration missions ("Mission From Planed Earth"); active (radar) and passive (radiometer) microwave sensors in the EOS and GSRP missions ("Mission To Planet Earth"); and Space Station and STS communication systems.

FOR FURTHER INFORMATION CONTACT:
Dr. Charles A. Raquet, Chief/Antenna & RF Systems Technology Branch - FTS 297-3471
Dr. Richard Q. Lee, Technical Manager for TI contract NAS3-25718 - FTS 297-3489

May 1991

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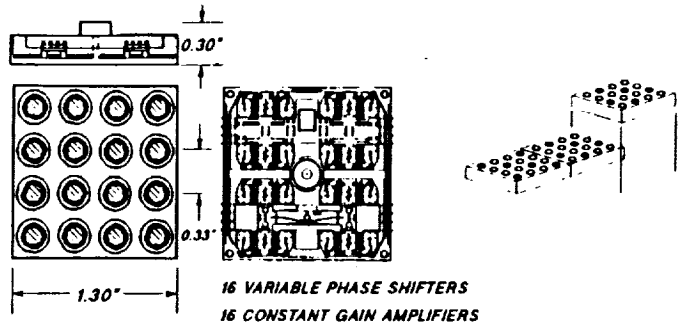
30 GHz MMIC SUBARRAY DEVELOPMENT

BENEFITS - Ka-BAND MMIC ARRAYS

HIGH POTENTIAL FOR:

- INCREASED COMMUNICATIONS SYSTEM CAPABILITY -
  - SCAN PERFORMANCE
  - DATA RATE
  - CONNECTIVITY
  - at
  - REDUCED SIZE, WEIGHT AND POWER
- INCREASED RELIABILITY
- LOWER COST

TEXAS INSTRUMENTS / NAS3-25718



16 VARIABLE PHASE SHIFTERS
16 CONSTANT GAIN AMPLIFIERS

SUBARRAY FEATURES

- HIGH DENSITY MULTILAYER "TILE" CONFIGURATION INTEGRATING 32 30 GHz CHIPS
- APERTURE COUPLED, CAVITY BACKED PATCH RADIATING ELEMENTS
- 4 BIT PHASE CONTROL OF EACH PATCH ELEMENT
- 1 mW INPUT / 1.5 W TRANSMIT POWER
- FULLY MODULAR SUBARRAY DESIGN
- HERMETICALLY SEALED SUBARRAY HOUSING

ACCOMPLISHMENTS

- KEY COMPONENTS DESIGN AND BREADBOARD TESTING SUCCESSFULLY COMPLETED
  - APERTURE COUPLED PATCH
  - MMIC CARRIER PLATE ASSEMBLY
  - BEAM FORMING NETWORK AND TRANSITIONS
- PHASE SHIFTERS FABRICATED AND CHARACTERIZED
- ASIC CONTROL CHIP DESIGN COMPLETED
- FINAL DESIGN REVIEW - JUNE 1991
- SCHEDULED COMPLETION DATE ADVANCED 6 MONTHS TO MARCH 1992

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Ka-BAND MMIC INSERTION TECHNOLOGY
30 GHz MMIC SUBARRAY DEVELOPMENT

Ka-band MMIC arrays have long been considered as having high potential for increased communications systems capability in terms of scan performance, data rate and connectivity at reduced size, weight and power consumption. Increased reliability (via graceful degradation) and lower cost have also been projected.

The 16 element 4 x 4 30 GHz MMIC subarray presently being developed under Texas Instruments contract NAS3-25718 is one of the most ambitious MMIC insertion programs yet attempted. The proof-of-concept array features a high density, multilayer "tile" configuration integrating thirty-two 30 GHz chips. The radiating elements are cavity backed, aperture coupled, linearly polarized microstrip patches. Beam steering over a +/- 30 degree cone and distributed power amplification are provided by a 4-bit phase shifter and a constant gain amplifier at each radiating element. The power amplifier is a direct descendant of an earlier LeRC sponsored TI MMIC amplifier development contract. The array will generate 1.5 watts of transmit power with 1 milliwatt of input power. The subarray design is fully modular, enabling the assembly of several subarrays into a larger array. The subarray housing will be hermetically sealed.

Excellent progress has been made on this contract, initiated in March 1990, with succesful completion of the design and breadboard testing of key components. These include the aperture coupled, cavity backed patch radiating elements, the MMIC carrier plate assembly, and beam forming network structures and transitions. The phase shifters have been fabricated and characterized and look very good, exhibiting a 3 db lower insertion loss than expected, along with excellent phase linearity. An custom ASIC control chip has been designed with a special feature which is expected to eliminate amplifier transient problems.

A final design review is scheduled for mid-June of 1991. Contract completion is now scheduled for March 1991, six months earlier than originally planned.

Following contractor testing the subarray will be tested in the LeRC Microwave Systems Laboratory (MS); demonstrated in a small ACTS fixed earth terminal experiment; and then installed in the NASA Learjet for the ACTS Aero Experiment.

FOR FURTHER INFORMATION CONTACT:
Dr. Charles A. Raquet, Chief/Antenna & RF Systems Technology Branch - FTS 297-3471
Dr. Richard Q. Lee, Technical Manager for TI contract NAS3-25718 - FTS 297-3489

May 1991

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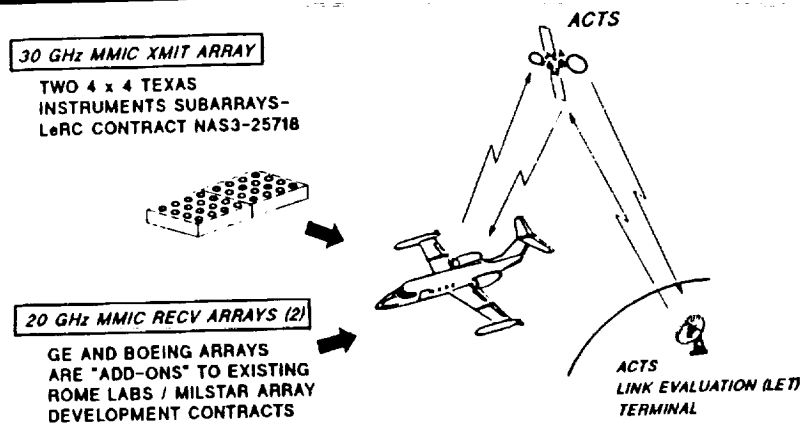
AEROSPACE TECHNOLOGY DIRECTORATE

ACTS AERO EXPERIMENT

NASA Lewis Research Center



EXPERIMENT FEATURES

- ELECTRONICALLY STEERED MMIC ARRAYS:
- LEARJET AIRCRAFT PLATFORM
- FULL DUPLEX VOICE LINK
- OPEN LOOP BEAM STEERING

OBJECTIVES

- DEMONSTRATE / EVALUATE MMIC ACTIVE PHASED ARRAYS ON AIRCRAFT PLATFORM
  - DEMONSTRATE FULL DUPLEX VOICE & DATA AT 2.4, 4.8 AND 9.6 Kbps
  - EVALUATE ANTENNA STEERING / AUTOMATIC ACTS BEAM TRACKING
  - MEASURE A/C-TO-E/T LINK PARAMETERS: BER, Eb/No, QUALITY, etc.
- DEMONSTRATE / EVALUATE ACTS TECHNOLOGY
  - EVALUATE PERFORMANCE OF ACTS SCANNING BEAM IN TRACKING AERONAUTICAL TERMINAL
  - EVALUATE EFFECTS OF ACTS WIDEBAND TRANSPONDER ON LOW DATA RATE SIGNALS

ACCOMPLISHMENTS

- LeRC SPACE ELECTRONICS DIVISION / ACTS PROJECT OFFICE PLANNING TEAM ESTABLISHED
- EXPERIMENT OPTIONS DEVELOPED
- ROME LABS / MILSTAR COMMITMENT TO EXPERIMENT OBTAINED FOR 20 GHz RECEIVE ARRAYS

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AEROSPACE TECHNOLOGY DIRECTORATE

ACTS AERO EXPERIMENT

NASA Lewis Research Center

The 4 x 4 30 GHz Texas Instruments MMIC subarray (NAS3-25718) is one of the keys to the ACTS Aero Experiment now jointly being planned by the Space Electronics Division and the ACTS Project Office. This experiment will demonstrate and evaluate MMIC active phase arrays on a Learjet aircraft platform. Full duplex voice and data links at 2.4, 4.8 and 9.6 Kbps from the aircraft terminal via ACTS to the ACTS link evaluation terminal (LET) will be demonstrated. The experiment will evaluate antenna steering and automatic ACTS beam tracking as well as link performance as measured by BER, Eb/No and voice quality. It will also demonstrate and evaluate ACTS technology including the performance of ACTS scanning beams in a tracking aeronautical terminal and the effects of the ACTS wideband transponder on low data rate signals. Automatic tracking within the limited scan range of the arrays will be provided by an open loop tracking system tying the aircraft inertial navigation unit to the arrays beam steering computer.

A 4 x 8 array consisting of two adjoining 4 x 4 Texas Instruments subarrays will form the 30 GHz transmitting antenna. The 20 GHz receive antenna will be provided via "add-on" tasks to existing Rome Labs/Milstar Program Office Integrated Circuit Active Phased Array Antenna (ICAPA) contracts (dual award) to GE and Boeing. Each contractor will develop a small 20 GHz MMIC receive array appropriate for the experiment; each array will be flown separately with the TI 30 GHz transmit array. This "add-on" task approach is very cost effective since the MMIC devices developed by GE and Boeing for the 20 GHz military band are sufficiently broadband to be used for the adjacent commercial 20 GHz band as well, and thus additional MMIC device development is not required. The resources for the "add-on" GE and Boeing arrays are being provided jointly by the ACTS Project Office and the Milstar Program Office. All arrays (TI, GE and Boeing) will be available in time for the ACTS experiment period beginning in 1993.

The LeRC Space Electronics Division and ACTS Project Office Planning Team is presently proceeding with developing detailed plans and schedules for array installation on the Learjet, for array control and interface systems and for baseband equipment. One option being considered may make use of appropriate subsystems of the JPL ACTS Mobile Terminal (AMT) for a portion of the experiment window.

FOR FURTHER INFORMATION CONTACT:
Dr. Charles A. Raquet, Chief/Antenna & RF Systems Technology Branch - FTS 297-3471
Robert J. Zakrajsek, Array/Aircraft Integration Coordinator for the ACTS Aero Experiment - FTS 297-3487
Dr. Richard O. Lee, Technical Manager for TI contract NAS3-25718 - FTS 297-3489

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May 1991

SOLID STATE COMPONENTS FOR SPACE COMMUNICATIONS SYSTEMS

RC — OAET

R&T SCOPE

Development of solid state, microwave components for future space communications systems (amplifiers, receivers, switches etc). Currently focused on GaAs MMIC based, high isolation, matrix switch at 3 GHz and a high efficiency, low cost 30 GHz amplifier for very small aperture terminals (VSAT's).

PAYOFFS

Smaller, lighter, more efficient, solid state devices (e.g., large periphery FET's) will enable smaller communication systems with reduced power requirements; MMIC implementation will yield an order of magnitude decrease in weight, power requirements and parts count over conventional hybrid switch matrices; solid state power amplifier development will enable production of Ka-band VSAT's at substantially lower costs than present systems

BENEFITS

Matrix switch - Lunar/Mars exploration; space station; commercial communications

Power amplifier - Commercial very small aperture terminals

TECHNICAL CHALLENGE

- Increase yield and numbers (lower cost) of Ka-band MMIC modules
- Increase efficiency, power and yield of large periphery Ka-band FETs
- Improve matrix switch packaging/modularity technology

SOLID STATE COMPONENTS FOR SPACE COMMUNICATIONS SYSTEMS

RC — OAET

APPROVED BUDGET	FY91	FY92	FY93	FY94	FY95
LeRC (\$K)	640	350	425	475	650

MAJOR MILESTONES

FY 1992 6X6 MMIC switch demonstrated (prototype)
FY 1994 Advanced MMIC matrix switch (modular, 10x10, on-chip buffers, 3 GHz)
FY 1994 SSPA, 30 GHz, 10 W prototype

AGENCY THRUST Primary: Operations
Secondary: Exploration

CENTERS LeRC **MISSION** Lunar/Mars exploration
Commercial communications

ADEQUACY OF RESOURCES

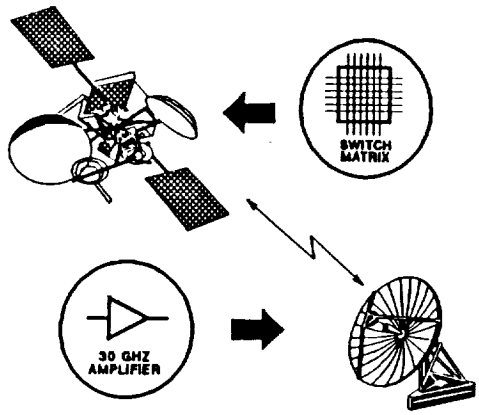
Current program is of excellent technical quality. Resources adequate only for advanced MMIC 10 x 10 switch. Initiation of fully packaged 10 W SSPA delayed to FY 95.

CURRENT STATUS Current technology readiness level: 3/4

AEROSPACE TECHNOLOGY DIRECTORATE

SOLID STATE COMPONENTS FOR SPACE COMMUNICATIONS SYSTEMS

NASA Lewis Research Center



OBJECTIVES:

SWITCH MATRIX

- TO DEVELOP A MODULAR 6X6 MMIC SWITCH MATRIX WITH FULLY INTEGRATED CONTROL ELECTRONICS EXTENDABLE TO LARGER MATRICES (96X96)

30 GHZ AMPLIFIER

- TO DEVELOP A 30 GHZ SOLID STATE POWER AMPLIFIER THAT CAN BE PRODUCED AT SIGNIFICANTLY LESS COST THAN A TWTA AND MAKE THIS TECHNOLOGY AVAILABLE TO U.S. MANUFACTURERS OF COMMERCIAL GROUND TERMINAL EQUIPMENT

BENEFITS:

SWITCH MATRIX

- REDUCE PARTS COUNT FOR LOWER COST
- SIZE AND WEIGHT ADVANTAGES FOR LARGER SIZE MATRIX

30 GHZ AMPLIFIER

- ENABLES LOWER COST GROUND TERMINALS

ACCOMPLISHMENTS:

SWITCH MATRIX

- 6X6 MMIC CHIPS FABRICATED AND RF TESTED
- HIGH ISOLATION CHIP HOUSING FABRICATED

30 GHZ AMPLIFIER

- CONTRACT AWARDED 10/19/90
- PDR HELD 2/20/91

AEROSPACE TECHNOLOGY DIRECTORATE

SOLID STATE COMPONENTS FOR SPACE COMMUNICATIONS SYSTEMS

NASA Lewis Research Center

ONGOING EFFORTS AT LeRC CONTINUE TO PROVIDE THE TECHNOLOGIES REQUIRED FOR EFFICIENT MICROWAVE LOW LEVEL SIGNAL SWITCHING AND LOW COST SOLID STATE MICROWAVE TRANSMITTERS FOR FUTURE COMMUNICATIONS SYSTEMS. THE OBJECTIVE OF THE FIRST EFFORT IS TO DEVELOP A MODULAR 6 INPUT BY 6 OUTPUT MMIC SWITCH MATRIX WITH FULLY INTEGRATED CONTROL ELECTRONICS EXTENDABLE TO LARGER MATRICES. THE APPROACH FOLLOWS THE SUCCESSFUL DEVELOPMENT OF A 3X3 MMIC SWITCH MATRIX WHICH UTILIZED A PROPRIETARY MMIC LAYOUT AND PACKAGING CONCEPT. THE CONTRACT WITH MICROWAVE MONOLITHICS INC. ENDS IN DECEMBER OF 1991. DELIVERABLE WILL BE A FULLY PACKAGED 6x6 MMIC SWITCH MATRIX OPERATING AT 3.0 - 6.0 GHz WITH 0 dB INSERTION LOSS AND 60 dB CHANNEL TO CHANNEL ISOLATION. VERY SIGNIFICANT IMPROVEMENTS WERE REALIZED OVER CONVENTIONAL (HYBRID) SWITCH MATRIX DESIGNS IN AREAS OF SIZE, WEIGHT AND POWER REQUIREMENTS.

THE OBJECTIVE OF THE SECOND EFFORT IS TO DEVELOP A 30 GHz SOLID STATE POWER AMPLIFIER WHICH CAN BE PRODUCED AT SIGNIFICANTLY LESS COST THAN A TRAVELING WAVE TUBE AND TO MAKE THIS TECHNOLOGY AVAILABLE TO U.S. MANUFACTURERS OF COMMERCIAL GROUND TERMINAL EQUIPMENT. THE CONTRACTUAL EFFORT WITH AVANTEK INC. WAS INITIATED IN OCTOBER OF 1990. DELIVERABLE WILL BE TWO POC MODEL AMPLIFIERS WITH OUTPUT OF 10 WATTS, OPERATING AT 30% EFFICIENCY. MAJOR CHALLENGES EXIST IN AREAS OF LARGE PERIPHERY FET's, DEVICE EFFICIENCY ENHANCEMENT AND POWER COMBINING TECHNIQUES. SUCCESSFUL COMPLETION OF THIS EFFORT WILL SIGNIFICANTLY LOWER THE COST OF THE KA BAND VERY SMALL APERTURE TERMINALS (VSAT).

TECHNICAL CONTACTS: SWITCH MATRIX : GENE FUJIKAWA, LeRC, (216) 433-3495 SSPA: GERALD J. CHOMOS, LeRC, (216) 433-3485

RC

COMMUNICATIONS PROGRAM

OAET

Digital Communications Technology

RC

DIGITAL COMMUNICATIONS TECHNOLOGY PROGRAM

OAET

R&T SCOPE

Development of advanced digital systems technologies for space communications. Includes: bandwidth- and power-efficient modulation and coding; onboard signal processing, switching, routing and autonomous network control; and cost-efficient ground terminals

PAYOFFS

Increased connectivity and data rates to 800 Mbps; Bandwidth efficiencies >1.7 bps/Hz; Power efficiency comparable to BPSK; Space-based, real-time video/data distribution; Increased service life to 20 years with graceful degradation

BENEFITS

Enables new class of interactive, integrated voice, video and data communication services. Digital implementation offers increased flexibility, programmability, reliability and improved size, mass, power consumption and performance over analog systems. Embedded artificial intelligence (AI) enables fault tolerance (FT) and autonomy

TECHNICAL CHALLENGE

- Very high capacity demodulation, switching and routing
- Programmability for future flexibility and standards compatibility
- Adaptive signal processing for changing channel environment
- Real-time fault detection, isolation and reconfiguration
- AI (expert systems, neural networks) insertion into onboard and ground systems

DIGITAL COMMUNICATIONS TECHNOLOGY PROGRAM

RC

OAET

APPROVED BUDGET	FY91	FY92	FY93	FY94	FY95
LeRC (K$)	2050	2375	2525	2675	2850

MAJOR MILESTONES

FY 1992	Complete 300 Mbps BCH codec ASIC (Flexible High Speed Codec)
	Complete 2 to 300 Mbps programmable digital modem (PDM)
	Award 800 Mbps/450 MHz modem contract (Very High Data Rate Modem)
	Initiate in-house fault-tolerent information switching processor (ISP)
FY 1993	Complete digital & optical multichannel demux/demod (MCDD) POC models
	Demonstrate combined modulation and coding via ACTS at 180 Mbps
	Initiate onboard autonomous network controller (ANC) with neural nets
FY 1994	Complete in-house 300-Mbps capacity ISP; Initiate 2-Gbps ISP demonstration model
	Demonstrate onboard processed FDMA/TDM services in SITE with 64-Kbps 84-channel slice
	Complete 800-Mbps/450-MHz VHDR modem
	Develop 150-Mbps ground terminal chipset and commercial experiment package
FY 1995	Complete 728-channel MCDD and ANC demonstration models

AGENCY THRUST Primary: Operations; Secondary: Exploration/Science

CENTERS LeRC **MISSION** ATDRSS, Commercial applications

ADEQUACY OF RESOURCES

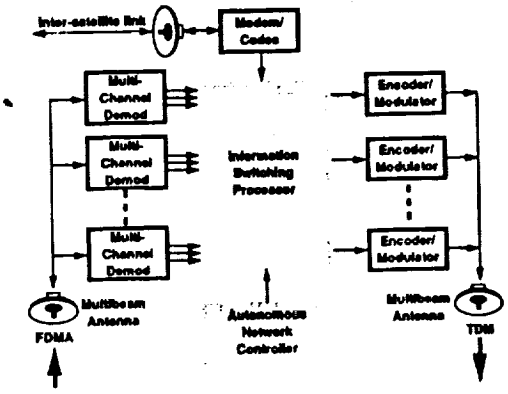
Adequate for POC; additional funding required for flight demo model development; Unique in-house DSP, ASIC, and digital systems development capability

CURRENT STATUS Technology readiness levels 3 to 5

AEROSPACE TECHNOLOGY DIRECTORATE

DIGITAL COMMUNICATIONS TECHNOLOGY PROGRAM

NASA Lewis Research Center

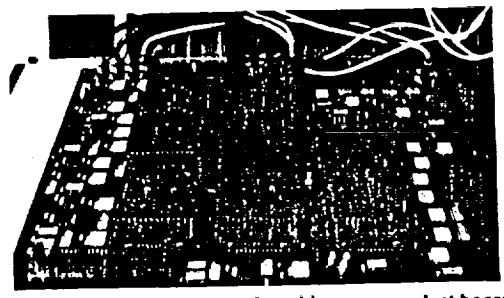


OBJECTIVES

- Increase modem bandwidth/power efficiency and data rates to 800 Mbps: codec throughput to 300 Mbps with soft decision gain
- Develop digital burst modem with programable rates (2-300 Mbps) and pulse-shaped modulation
- Enable onboard processing of low-cost FDMA ISDN voice, data, and video with multichannel demods, onboard circuit/ packet switch and network control
- Apply fault tolerance and autonomy to onboard processing for increased capability and service life

ACCOMPLISHMENTS

- Fastest known Viterbi decoder at 225 Mbps
- 160 Mbps trellis-coded 8-PSK demo 2 bps/Hz
- ACTS evaluation terminals at 220 Mbps
- Contracts for programmable digital modem, flexible high-speed codec, digital and optical multichannel demux/demods
- In-house capability for DSP, CAD, ASIC, Neural networks, and expert systems



COSMAT Labs -Viterbi decoder add-compare-select board

CD-91-55403

DIGITAL COMMUNICATIONS TECHNOLOGY PROGRAM

The objective of the program is to apply advanced digital signal processing and switching technology to space communications. This involves development from the conversion of theory into proof-of-concept models through flight-qualifiable subsystems. Digital communications technology is inserted into both the space and ground segments to dramatically improve the size, mass, power consumption, and performance compared to analog counterparts. At the same time, digital implementations offer reduced cost in quantity and are generally immune from aging, drift, and alignment problems associated with analog components. Through the use of fault-tolerant design and imbedded artificial intelligence, the capability, reliability, and reconfigurability of onboard systems is greatly improved.

The program focuses on three major areas: advanced modulation and coding; space-based-processing and control; and ground based processing and control. The goals of the modulation and coding focus is to increase data rates to 800 Mbps through planned 450 MHz links, apply digital signal processing to modems for significant improvement in implementation loss and application to a variety of programs without redesign, and enable a new class of interactive communications services through onboard demodulation of thousands of FDMA uplinks from low cost terminals.

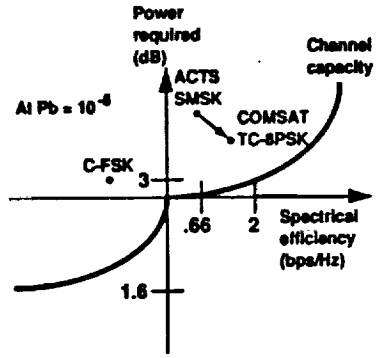
An information switching processor (ISP) that enables real-time interactive voice, video, and data communications for tens of thousands of users and an autonomous network controller (ANC) onboard the satellite are the goals of the second program focus. The ISP will offer circuit- and packet-switched services compatible with emerging commercial ISDN and government CCSDS standards. The ISP is also an enabling component of a direct-to-user data distribution satellite for NASA missions. The ANC performs several of the network control function formerly performed in a costly master control station on the ground. This significantly improves the time to reconfigure satellite resources for traffic demand and offers the benefits of spacecraft health monitoring including fault detection, isolation, diagnosis, and recovery. All onboard processing systems of the future will require imbedded fault tolerance and autonomy to assure the proper functioning of the computationally complex subsystems over the life of the satellite.

The goals of the ground based processing and control focus of the program are to decrease the cost of terminals and increase their capability, while maintaining industry standard interface compatibility. Single chips for the modulation, coding, access control, and terrestrial interface will enable low cost communications services. Expert systems are being applied to diagnose ground terminal failures and provide autonomous operation.

In-house laboratories for digital signal processing; computer-aided design, simulation, and circuit fabrication; digital subsystems development and performance evaluation; and expert systems and neural network applications development enable a collaborative effort with industry and university partners.

NASA Lewis Technical Contacts: Joseph L. Harrold (216) 433-3499; James M. Budinger (216) 433-3496

ADVANCED MODULATION AND CODING



Shannon-Hartley channel capacity curve

OBJECTIVES

- Bandwidth efficient coded modulation for > 2 bps/Hz; New combinatorial FSK techniques more power efficient than BPSK; Demonstration via ACTS
- Increase modem rates to 800 Mbps; Soft decision codec to 300 Mbps; Least reliable bit codec to 1 Gbps
- Digital implementation for programmable data rates, acquisition modes, and pulse-shaped modulation
- Digital and optical multichannel demux/demods for onboard processed FDMA/TDM

ACCOMPLISHMENTS

- Trellis-coded 8-PSK and 16-QAM modems from COMSAT and TRW; Bit selective coded 8-PSK and 16-CPFSK from Ford and Harris
- In-house digital trellis-coded modem/codec with multi-symbol baseband pulse shaping for ISI control and non-linear pre-compensation
- Five contracts in place, four completed, two planned, and five grants

COMSAT Trellis-codec 8-PSK modem/codec

CD-91-55404

ADVANCED MODULATION AND CODING

The objective of the program focus on advanced modulation and coding is to apply high-speed digital electronics to the modulation and coding functions to significantly increase the data rates and advanced digital signal processing techniques to improve the link bandwidth and power efficiency for commercial and NASA mission applications. The program focus has multiple contracts, grants and in-house activities in each of the four areas listed below.

Bandwidth and Power Efficient Modems: Maximizing the data throughput for all future bandwidth (BW) and/or power constrained commercial satellite and NASA spacecraft links is the goal of this activity. Contracts with Ford, TRW, COMSAT, and Harris were completed in 1990 to demonstrate 2 bps/hz BW efficiency at bursted data throughput from 160- to 200-Mbps. An 800-Mbps to 1-Gbps modem contract is planned to demonstrate more efficient use of planned ATDRSS 450-MHz links. A U. of California, Davis grant has developed a new class of modulation techniques for BW and power constrained, non-linear links. An in-house modem and codec will demonstrate the BW efficiency of multiple-symbol digitally waveshaped quadrature modulation schemes at 50 Mbps and power efficiency of direct-digital-synthesized combinatorial FSK at 300 Mbps.

High Speed Codecs: Low-overhead, high data rate codecs that can operate on short bursts of data from multiple sources are required for future missions. COMSAT Labs has developed the fastest known Viterbi decoder for Lewis at 225 Mbps. Harris is under contract to develop a 300 Mbps codec that uses hard- and soft-decision information at code rates $\geq 7/8$ for as much as 5 dB coding gain on bursts as short os 256 bits. U. of Southern California is funded to investigate co-designed coding, modulation, and equalization. An in-house project culminating in an ACTS experiment will demonstrate the performance of trellis-coded and least reliable bit coded modulation using commercial RS decoders and COMSAT modem.

Digital Modems: Digitally implemented modems offer benefits of programmability, immunity from aging, drift, and alignment problems, and low-cost in quantity. COMSAT Labs is developing an ASIC-based modem with programmable data rates (2- to 300-Mbps), modulation schemes (m-ary PSK, MSK, 16-QAM), and acquisition modes (dependent-, independent-burst, and continuous). A contract is planned for a signal chip m-PSK burst demod at 50 Mbps for VSAT processing of TDM downlinks. Ohio U. is developing multi-symbol aperture digital pulse shapes for ISI control and pre-compensation for non-linear channel distortions. In-house activities use commercial digital signal processing neural networks for adaptive demodulation.

Multichannel Demultiplexer/Demodulator: The MCDD is an enabling technology for a new class of onboard-processed, interactive voice,video, and data services using low-cost FDMA terminals. TRW is developing a hierarchical time-domain FFT based MCDD and Westinghouse id pursuing a heterodyne optical Bragg cell approach. Small business, Amerasia Technology, is developing an MCDD using the SAW-based chirp Fourier Transform technique. U. of Toledo is designing a parallel/pipeline FFT-based transmultiplexer in ASICs, and U. California is applying fault-tolerant deign to FFTs.

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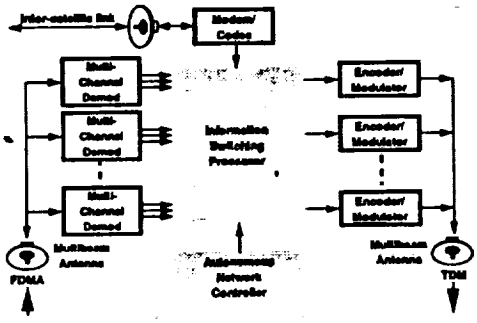
AEROSPACE TECHNOLOGY DIRECTORATE

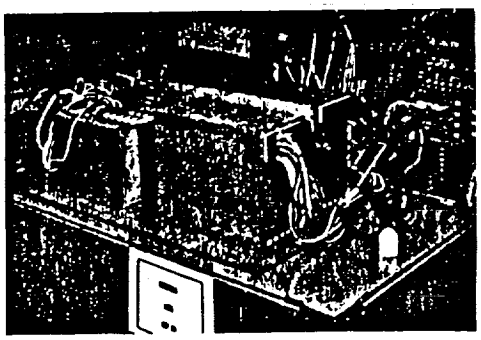
ONBOARD PROCESSING AND CONTROL

NASA Lewis Research Center

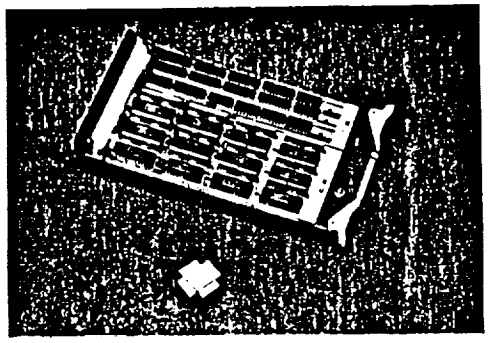


OBJECTIVES

- **Develop 2 Gbps capacity information switching processor and autonomous network controller for mesh VSAT network and ISL data distribution**
- **Enable onboard processing of circuit and packet switched voice/video in ISDN and CCSDS formats**
- **Apply fault tolerant design and neural network based intelligence for autonomous operation**



ACTS - Motorola EM baseband processor



Honeywell Inc. 700-Mbps 250-mW 64:1 Demultiplexer

CD-91-55405

ONBOARD PROCESSING AND CONTROL

The objective of the program focus on onboard processing and control is develop digital subsystems for autonomous switching and routing of communications data. Initial activity has been distributed between two primary onboard processing functions, the data switch and the onboard control, described in more detail below. Starting primarily as an in-house activity to demonstrate a fault-tolerant switcher/router, this activity is planned to grow into a contractual program for development of critical components and subsystems in a flight-qualifiable implementation.

Information Switching Processor: The ISP will provide circuit- and packet-switched connectivity to tens of thousands of users in a format compatible with emerging ISDN and CCSDS standards, and enable real-time distribution of intersatellite-linked NASA mission data direct to principal investigators. The ISP will advance and integrate many of the onboard processing technologies previously demonstrated under this program. The baseband processor developed by Motorola in the mid-1980s proved the onboard switching and processing concepts to be employed on the ACTS. In the late 1980s, Honeywell demonstrated significant improvements in speed, size, and power consumption of custom GaAs over discrete Si ECL logic in a 64 bit demultiplexer. More recently, Microwave Monolithics Inc. developed matrix switches at 3- and 30-GHz and is now including buffer amplifiers for 0 dB insertion loss. An SBIR contract with Mendez R&D Associates will develop an optical 8x8 crosspoint switch which uses code division multiple access techniques. A SCAR contract with COMSAT Labs has investigated onboard processing architectures suitable for fast-packet switching of broadband ISDN data, and a proof-of-concept model fast packet switch is planned in future contract phases. Two task order contracts have been established to identify competing architectures, analyze feasibility, perform performance tradeoffs, and identify critical components of an onboard processed communications network. Finally, the in-house switching demonstration will demonstrate a 4x4 baseband packet/circuit switch with fault-tolerant features as a precursor to a demonstration model ISP.

Autonomous Network Controller: The onboard ANC will perform some subset of the features normally performed by a ground-based network control computer to significantly improve the traffic flow control, reduce call setup time and resource contention, and enhance the reliability of future satellite-based communications networks. In addition to the network and traffic management tasks, the ANC can also provide extensive spacecraft health and performance monitoring and perform fault detection, isolation, diagnosis, and recovery. An in-house investigation into the use of neural network to optimize the reconfiguration and throughput of a non-blocking, high-capacity switch is under way.

An onboard processing technology workshop is planned for late summer to enable the commercial communications industry to identify critical and enabling digital and optical signal processing components appropriate for NASA development and suitable for commercial insertion. A space communications technology conference focussing on onboard processing with over forty papers will be hosted by Lewis in November 1991.

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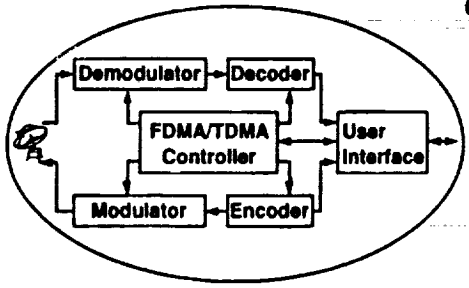
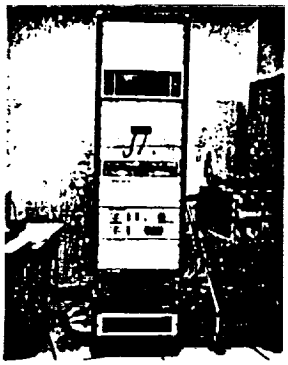
GROUND-BASED PROCESSING AND CONTROL

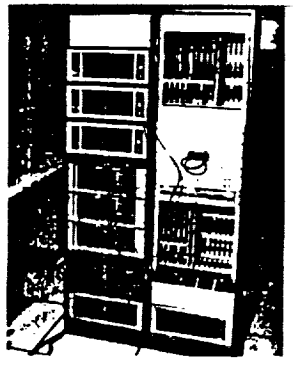


OBJECTIVES

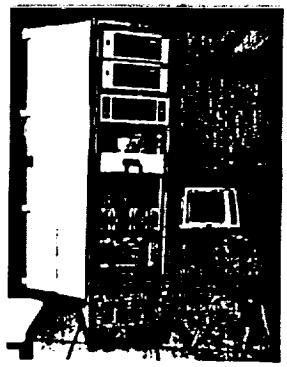
- **Industry standards compatible terrestrial interfaces for circuit and packet switched voice/video/data**
- **Flexible FDMA/TDM controller/interface ASIC chipset for low cost and high reliability**
- **Replace existing VSAT indoor unit modem, controller, and interface for new class of interactive services**
- **Apply imbedded fault-tolerance and expert systems for autonomous operation**



SITE 220 Mbps Bit-Error-Rate Measurement Systems



SITE Three-User, 220 Mbps TDMA Digital Ground Terminal



ACTS 220/110 Mbps Digital Link Evaluation Terminal

CD-91-55466

GROUND-BASED PROCESSING AND CONTROL

The objective of the program focus on ground-based processing and control is to apply advances in digital logic, digital signal processing, microcontrollers, fiber optics, and expert systems to the digital portions of satellite ground terminals and network control.

Starting in 1984, in-house terminal design and development has progressed from a modulated data BER measurement system used to characterize the effect of microwave components on BER performance, through a three-user TDMA burst data terminal supporting voice, data and video services, to a link evaluation terminal to characterize the on-orbit performance of the ACTS high burst rate system. An enhanced version of the TDMA terminal with internal modular design for capacity expansion, an optical bus interface for multiple users, and built-in self-test for improved reliability is under development. All versions of the terminals were designed around a set of 220/110 Mbps serial minimum shift keyed (SMSK) modems developed by Motorola as a predecessor of those to be flown on the ACTS. In-house schematic capture, simulation, board fabrication, and ASIC development tools are used in this activity. Expert systems have been applied to diagnose terminal failures and document terminal designs.

Planned ground terminal development activities include: a programmable controller for FDMA/TDMA uplinks and TDM downlinks compatible with the onboard processing architectures currently under development; terrestrial interfaces that convert industry standard data formats, including packet switched data, into formats suitable for satellite network transmission; and new digital terminal architectures for extremely low-cost single user and multiple user applications.

Future network control activities will focus on distributed (space-ground) processing of user communication traffic and satellite resource management, fault detection, isolation, and reconfiguration.

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RC **COMMUNICATIONS PROGRAM** OAET

Optical Communications Technology

HIGH POWER DIODE LASER FOR OPTICAL COMMUNICATIONS

RC OAET

R&T SCOPE

Develop, demonstrate, lifetest and space qualify high power and high data rate semiconductor diode lasers for Optical Communication applications

PAYOFFS

Improved communications data rate, range of communications and overall data handling capability for data communication systems

BENEFITS

Provide means to transmit high data/rate information from satellite sensor systems to provide timely analysis of sensor information

TECHNICAL CHALLENGE

- Demonstration of semiconductor laser suitable for all optical communications
- Development of high power/high modulation rate semiconductor lasers
- Demonstration of single spatial and spectral mode semiconductor lasers
- Demonstration of long lifetime and stable semiconductor lasers

HIGH POWER DIODE LASER FOR OPTICAL COMMUNICATIONS

RC OAET

APPROVED BUDGET	FY91	FY92	FY93	FY94	FY95
L (K$)	170	170	170	170	170

MAJOR MILESTONES

FY 1991	Demonstrated 1.3 W Monolithic Active Grating-Master Oscillator Power Amplifier (MAG-MOPA) laser and 800 MHz modulator
FY 1992	Demonstrate 2 W MAG-MOPA with >1 GHz modulation
FY 1993	Demonstrate multi-electrode modulator MAG-MOPA
FY 1994	Demonstrate 5 Watt single spatial/spectral MAG-MOPA
FY 1995	Demonstrate MAG-MOPA with 4 GHz modulation
FY 1996	Demonstrate laser stability/lifetime

AGENCY THRUST Primary: Science
Secondary: Space Exploration

CENTERS LaRC **MISSION** EOS-MTPE;
Lunar/Mars exploration

ADEQUACY OF RESOURCES

Limited resources, joint program with SDIO/$300K/YR

CURRENT STATUS Technology readiness level: 2/3

RC

TRANSMITTERS AND RECEIVERS FOR OPTICAL COMMUNICATION

OAET

R&T SCOPE

Develop optical transmitter and receiver components and subsystems for near-Earth intersatellite communications

PAYOFFS

High power lasers and high sensitivity detectors are an enabling technology for intersatellite optical links which provide improved data capacity and reduced power, size and weight requirements

BENEFITS

Enables data intensive earth observing science missions, provides high capacity international trunk lines for international telecommunications and television services. The developed laser and detector technology is applicable to NASA science missions using laser-based instruments, and it will benefit future commercial satellite communications efforts

TECHNICAL CHALLENGE

- High power (1 Watt), high bandwidth (1 Gbps), high efficiency (5%) lasers
- High gain (500), low noise (k=.004), high sensitivity (pW) high quantum efficiency (>30%), laser wavelength compatible detectors

RC

TRANSMITTERS AND RECEIVERS FOR OPTICAL COMMUNICATION

OAET

APPROVED BUDGET	FY91	FY92	FY93	FY94	FY95
GSFC (K$)	480	480	528	580	640

MAJOR MILESTONES

FY 1991	220 Mbps direct detection receiver 0.5 W semiconductor benchtop MOPA laser 700 MHz bandwidth, low noise APD and pre-amp
FY 1992	1 W, 1 Gbps diode-pumped Nd-doped laser
FY 1993	1 W, 1 Gbps monolithic semiconductor MOPA laser
FY 1994	High-Q.E. GHz-bandwidth, Nd compatible detector
FY 1995	Space-qualifiable 1 W, 1 Gbps laser transmitter

AGENCY THRUST Primary: Science
Secondary: Exploration

CENTERS GSFC **MISSION** EOS, ATDRSS

ADEQUACY OF RESOURCES

Recent personnel additions add increased capability to GSFC's heritage in optical communication

CURRENT STATUS Technology readiness level: 3
State of the art is continually advancing

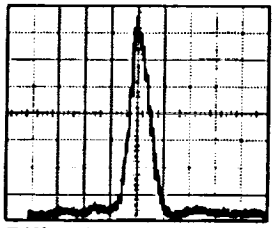
NASA

Lasers and Detectors for Optical Communication

Laser Transmitter

High Power Semiconductor Laser Master Oscillator/Power Amplifier (MOPA)

Custom Broad Area Semiconductor Optical Amplifier

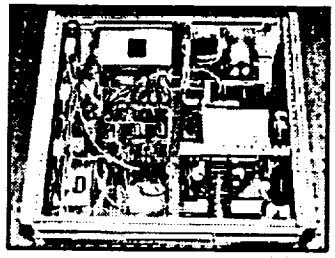


Nearly Diffraction Limited 480 mW CW Far-Field Output

C459.01 BD90

Receiver Detector

High Performance Optical Detector/Receiver



220 Mb/s Direct Detection Receiver

Hybrid Integrated Circuit

EG&G (Formerly RCA/GE) Super Low Ionization K-Factor (SLIK) Low Noise Avalanche Photodiode Detector

Gigabit Logic Model 16G071 700 MHz Preamp

700 MHz Pre-Amplifier and Low Noise APD Hybrid

GSFC

RC1 LASERS AND DETECTORS FOR OPTICAL COMMUNICATION — OAET

Laser Advancement: *high power semiconductor laser master oscillator/power amplifier (MOPA)*

Objective: The objective of this work is to develop high power, high efficiency, high bandwidth laser transmitters suitable for intersatellite optical communications links. The near term goals for this technology are to demonstrate a benchtop laser which can be digitally intensity modulated at 1 Gbps, has a wall-plug efficiency of (> 5 %) including support electronics, has a wavelength compatible with high bandwidth, sensitive detectors and provides in excess of one watt of optical average power.

Technology: The technology is shown in the graphic is a custom broad area semiconductor laser amplifier which has been anti-reflection coated for use as an optical amplifier. The device was custom manufactured for NASA-Goddard by Spectra-Diode Laboratories(SDL). The device is an aluminum gallium arsenide (AlGaAs) multiple quantum well semiconductor chip with a 400 micron wide active area (stripe). The design philosophy is to modulate a low power "master oscillator" laser at the desired data rate and to use an optical "power amplifier" to boost the optical power. This eliminates the need for high current electronic drivers while preserving the highly desirable optical and spectral properties associated with the laser's lowest order transverse spatial modes.

Status: NASA-Goddard is [illegible] semiconductor laser technology at many levels. We have operated the single SDL lasers at 2 ns pulse width with 400 mW of peak power [illegible] age power. Goddard has constructed an in-house MOPA as shown. Goddard also has a grant at the University of Maryland to investigate [illegible] coupled semiconductor MOPA. In addition, Goddard is monitoring the SCAR effort at SDL for the production of a monolithic semiconductor MOPA on a single GaAs chip. SDL recently showed 0.7 W of average power from this device.

Accomplishments: The MOPA shown constructed at Goddard delivered 480 mW of average power in a single diffraction limited beam using an SDL master oscillator and the broad area power amplifier. This laser can be used for coded laser radar and lidar as well as communication.

Receiver/Detector Advancement: *220 Mb/s direct detection receiver with SLIK APD and wideband pre-amp hybrid circuit*

Objective: The objective of this effort is to develop high sensitivity wideband optical detector and receiver technology suitable for intersatellite optical communications links. The near term goal for the detector is to achieve picowatt sensitivity at the 800-860 nm wavelengths, high quantum efficiency (> 80 %), low noise (k-factor=.004) and to couple to a wideband (700 MHz) low noise preamplifier. The goals for the receiver are to investigate realistic optimum receiver component configurations to achieve high probability of detection at 325 Mb/s data rates.

Technology: The present detector technology shown is a high performance Super Low Ionization K-factor (SLIK) avalanche photodiode detector (APD) manufactured by EG&G (formerly RCA/GE). NASA-Goddard has extended the high sensitivity detector state-of-the-art by the development of a custom hybrid integrated circuit (IC) consisting of two commercial components: an EG&G SLIK APD and a Gigabit Logic 700 MHz preamplifier. A 220 Mb/s quaternary pulse position modulation (Q-PPM) maximum likelihood optical receiver has been constructed on a grant at the Johns Hopkins University.

Status: EG&G recently began the construction of the EG&G SLIK APD and a Gigabit Logic 700 MHz preamplifier hybrid IC. Goddard will be receiving eight ICs.

Accomplishments: The 220 Mb/s Q-PPM maximum likelihood receiver is fully operational and is awaiting the integration of the hybrid IC detector/pre-amp to achieve maximum sensitivity. The detector/pre-amp can be used for laser radar and lidar at 1.06 microns as well as communications at 800-860 nm.

Technical Contact: Michael A. Krainak (301) 286-2646

PLANETARY OPTICAL COMMUNICATION

RC

OAET

R&T SCOPE

Components and subsystems for deep space communications systems on future planetary spacecraft

PAYOFFS

Increased data rates (10-100X), smaller and lighter weight spacecraft communications systems (1/10 volume, 1/2 mass), improved navigational tracking

BENEFITS

Enables extensive orbital mapping and piloted missions to the planets, reduced volume expands launch vehicle possibilities, permits tracking of spacecraft range and bearing from a single Earth station, enables light science

TECHNICAL CHALLENGE

- Highly efficient, modulated lasers with adequate power (2 watts, 5% overall efficiency)
- Deep space ack/trk strategies (multi-pixel Earth tracking)
- Stray light rejection at small Sun-Earth angular separation
- Low mass/power for entire comm subsystem (<50 kg, <50 W)

PLANETARY OPTICAL COMMUNICATION

RC

OAET

APPROVED BUDGET	FY91	FY92	FY93	FY94	FY95
JPL (K$)	1100	1380	1450	1500	1600

MAJOR MILESTONES

FY 1991	Scope breadboard tests; 100 Kbps coherent receiver demo; composite optical bench
FY 1992	2-W laser demo; 100 Mbps coherent demo; extended source ack/trk
FY 1993	Heterodyne spatial ack/trk; 2-W laser module development
FY 1994	10 Mbps laser modulator; ack/trk detector module development
FY 1995	Coherent transponder architectural design; integrated ack/trk communication demonstration

AGENCY THRUST Primary: High-rate communications/operation
Secondary: Space exploration

CENTERS JPL **MISSION** Lunar/Mars exploration; robotic planetary exploration

ADEQUACY OF RESOURCES

Existing level of effort cannot meet program need dates.
Current program is of excellent technical quality.

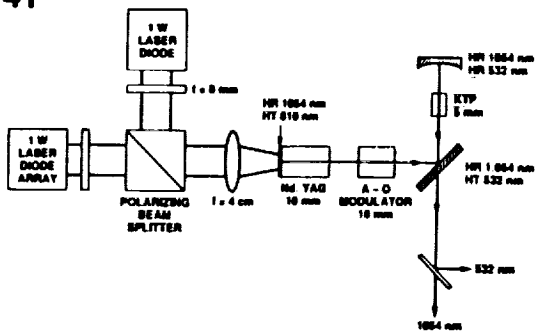
CURRENT STATUS Current technology readiness level

SPACE LASER COMMUNICATION TECHNOLOGY

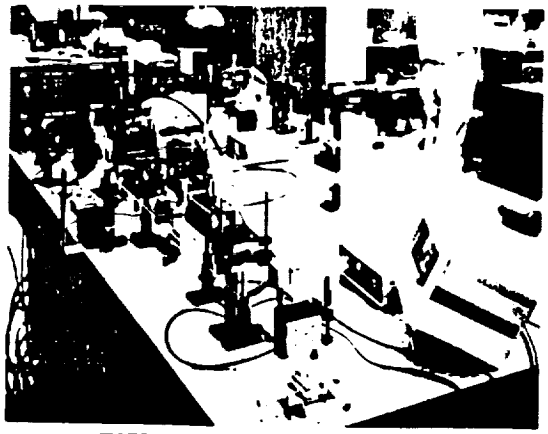
JPL

506-59-41

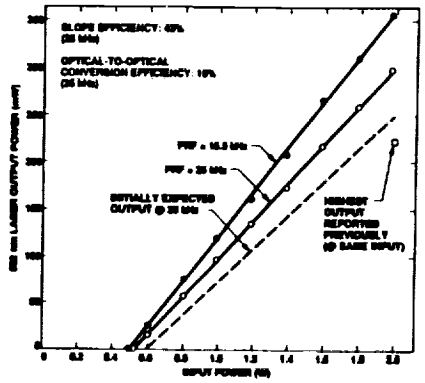
- MODULATED AND FREQUENCY-DOUBLED OUTPUT OF A DIODE-LASER-PUMPED SOLID-STATE LASER USING AN ACOUSTO-OPTICAL Q-SWITCH, AND A KTP FREQUENCY-DOUBLER
- OBTAINED 340 mW OF 532 nm RADIATION WITH 25 nsec PULSEWIDTH AND 20 KHz REPETITION RATE



SCHEMATIC DIAGRAM OF THE SET-UP



PICTURE OF THE SET-UP



AVERAGE POWER VS REP. RATE

SPACE LASER COMMUNICATION TECHNOLOGY

JPL

506-59-41

THE OBJECTIVE OF THIS TASK IS TO DEVELOP TECHNOLOGIES THAT WILL ENABLE OPTICAL COMMUNICATIONS DATA RETURN FROM FUTURE DEEP-SPACE MISSIONS. OPTICAL COMMUNICATIONS WILL PERMIT SUBSTANTIALLY INCREASED (10-100X) DATA RETURN RATES WITH SUBSYSTEMS THAT ARE SMALLER AND LESS MASSIVE (1/10 VOLUME AND 1/2 MASS) THAN THE CURRENT RADIO FREQUENCY SYSTEMS. ONE OF THE KEY INGREDIENTS FOR SUCH FUTURE SYSTEMS IS A HIGHLY EFFICIENT LASER TRANSMITTER. THE LASER MUST HAVE HIGH OVERALL POWER EFFICIENCY, OUTPUT RADIATION IN SPECTRAL REGIONS OF HIGH PHOTODETECTIVITY (e.g. 532 nm WAVELENGTH) AND PRODUCE MODULATED PULSES WITH HIGH PEAK POWER LEVELS.

THE ACCOMPANYING FIGURE SHOWS A HIGHLY EFFICIENT LASER DEVELOPED FROM A JPL PATENTED LASER ARCHITECTURE. THE OBJECTIVE OF THE TASK WAS TO PRODUCE 0.25 WATTS OF PULSED GREEN (532 nm) LIGHT.

TWO 1-WATT DIODE LASERS WERE USED TO PUMP AN ACOUSTO-OPTICALLY Q-SWITCHED Nd:YAG LASER CAVITY. INTRACAVITY FREQUENCY-DOUBLING RESULTED IN 532 nm PULSES WITH 340 mW OF AVERAGE POWER AND 19% OPTICAL-TO-OPTICAL CONVERSION EFFICIENCY.

A FOLDED CAVITY WAS USED TO PUMP THE Nd:YAG CRYSTAL. THIS CRYSTAL AND A 1-cm LONG ACOUSTO-OPTICAL Q-SWITCHER WERE LOCATED IN ONE ARM OF THE CAVITY WHILE A POTASSIUM TITANYL PHOSPHATE (KTP) CRYSTAL WAS PLACED IN THE OTHER ARM. THE 532 nm RADIATION WAS TRANSMITTED THROUGH THE FOLD MIRROR WHILE THIS AND OTHER CAVITY MIRRORS HAD HIGH REFLECTANCE AT 1064 nm. WITH THIS CAVITY ARRANGEMENT THE 532 nm RADIATION PASSED THROUGH THE KTP CRYSTAL AND AVOIDED BOTH THE Q-SWITCHER AND THE YAG CRYSTAL.

PULSED 532 nm LASER RADIATION WITH AN AVERAGE POWER OF APPROXIMATELY 340 mW WAS OBTAINED AT 10 KHz REPETITION RATE. PULSE-WIDTHS VARIED IN THE RANGE OF 20 TO 30 nsec DEPENDING ON THE LASER REPETITION RATE. THE OPTICAL (810 nm) TO OPTICAL (532 nm) CONVERSION EFFICIENCY WAS APPROXIMATELY 19%. WITH THE SAME INPUT DIODE-LASER POWER, THE CONTINUOUS-WAVE POWERS WERE 900 mW AND 165 mW FOR 1064 nm AND 532 nm WAVELENGTHS RESPECTIVELY.

DESIGNS ARE PRESENTLY BEING EVALUATED TO EXTEND THE OUTPUT POWER CAPABILITY TO 2-WATTS. CHALLENGES INCLUDE OPTICS DESIGN FOR EFFICIENT PUMP-TO-CAVITY COUPLING, THERMAL CONTROL OF THE HIGHER-POWER PUMP DIODES AND LASER CRYSTAL, COMPENSATION FOR THERMAL LENSING IN THE CAVITY, HIGH SPEED MODULATION OF THE OUTPUT AND IMPROVING THE OVERALL WALLPLUG EFFICIENCY.

TECHNICAL CONTACT: J. R. LESH, FTS 792-2766

JPL Integrated Optical Communication Test Bench

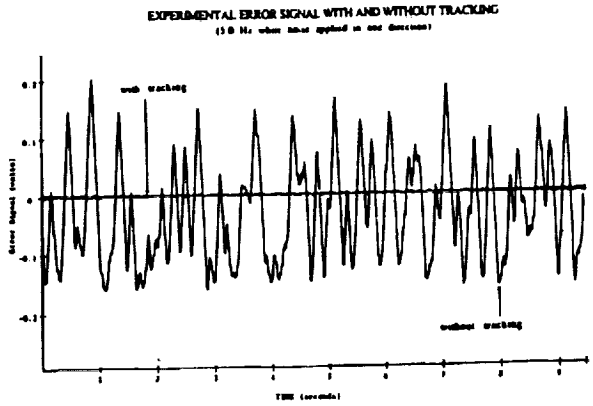
(506-44-21)

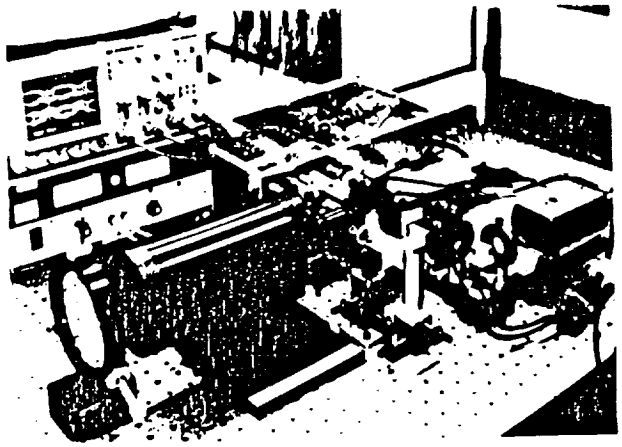
- DEVELOPED ALGORITHM, AND FABRICATED ELECTRONICS FOR POINT SOURCE ACQUISITION AND TRACKING ON THE TEST BENCH

  USES CCD CAMERA FOR ACQUISITION AND QUAD AVALANCHE PHOTO DIODE FOR TRACKING THE TARGET

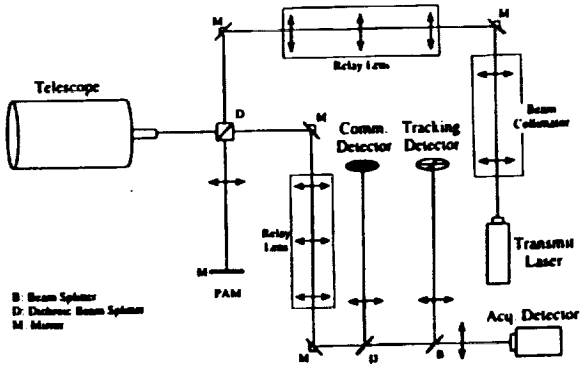
- IMPLEMENTED TEST SET-UP TO SIMULATE SPACECRAFT VIBRATION

- DEMONSTRATED ACQ/TRACK UNDER VIBRATION
  TRACKING BANDWIDTH : > 100 Hz
  ACQUISITION TIME : < 4 SECONDS
  VIBRATION SUPPRESSION : > 43 dB AT 1 Hz





SCHEMATIC OF TEST BENCH



INTEGRATED OPTICAL COMMUNICATION TEST BENCH

SEPTEMBER 1990

SCHEMATIC AND PICTURE OF THE CURRENT TEST BENCH SET-UP TO EVALUATE INDIVIDUAL COMPONENTS OF A DEEP SPACE OPTICAL COMMUNICATION TRANSCEIVER PACKAGE ARE SHOWN. THE PACKAGE CONSISTS OF AN ACQUISITION AND TRACKING SYSTEM, A TRANSMIT AND RECEIVE SECTION AND A POINT-AHEAD MONITORING SYSTEM. TWO PAIRS OF SCANNING MIRRORS ARE USED TO TRACK OUT SPACECRAFT VIBRATION AND JITTER. A CCD IS USED FOR ACQUISITION WHILE A QUADRANT AVALANCHE PHOTO DIODE (QUAD APD) IS USED FOR HIGH BANDWIDTH POINT SOURCE TRACKING.

DURING FY'1990, TRACKING ELECTRONICS WERE DESIGNED, BUILT AND TESTED. A PAIR OF SCANNING MIRRORS WERE USED TO SIMULATE SPACECRAFT VIBRATION AND JITTER ON THE SOURCE RATHER THAN ON THE TRANSCEIVER PACKAGE ITSELF. POINT SOURCE TRACKING HAS BEEN DEMONSTRATED WITH AND WITHOUT VIBRATION. A TRACKING BANDWIDTH OF GREATER THAN 100 Hz HAS BEEN ACHIEVED. NOISE REJECTION OF GREATER THAN 43 dB AT 1 Hz AND 25 dB AT 10 Hz WAS ACHIEVED WITH THE TRACKING ELECTRONICS. THE ERROR SIGNALS FROM THE QUAD APD WITH AND WITHOUT TRACKING WHEN 5.0 Hz WHITE NOISE IS APPLIED TO THE MIRRORS IS SHOWN. ACQUISITION PLUS HAND-OVER TIME WAS LESS THAN 4 SECONDS AND RE-ACQUISITION TIME AFTER LOSS OF LOCK ON TARGET WAS LESS THAN 5 SECONDS.

WORK ON INCREASING THE BANDWIDTH TO GREATER THAN 1 KHz AND RESOLUTION TO LESS THAN 1 μRAD IS IN PROGRESS.

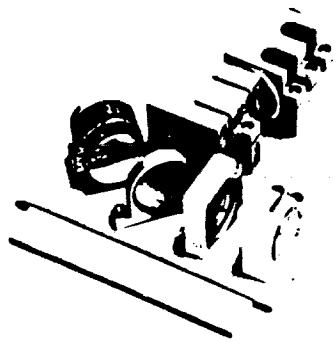
TECHNICAL CONTACT: JAMES R. LESH, JPL, (818) 354-2766 or FTS 792-2766

SCOPE (SMALL COMMUNICATIONS OPTICAL PACKAGE EXPERIMENT) BREADBOARD

JPL

506-59-41

- DESIGNED AND BUILT A RECEPTION AND MEASUREMENT SYSTEM TO DEMONSTRATE AND CHARACTERIZE THE PERFORMANCE OF THE SCOPE BREADBOARD
- COMPLETED OPTICAL LINK BIT ERROR RATE MEASUREMENTS AT A DATA RATE OF 1 mbits/s
- EXPERIMENT AND THEORY ARE IN GOOD AGREEMENT



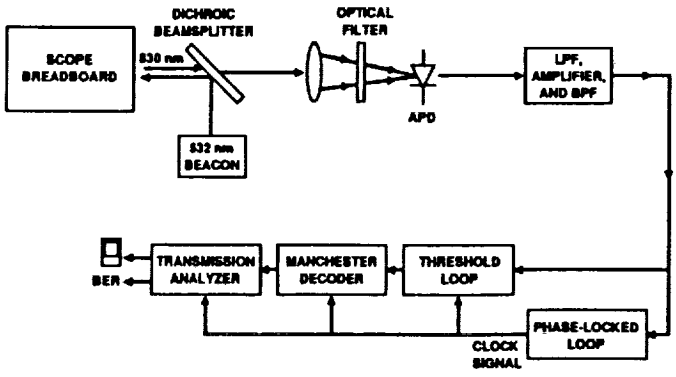
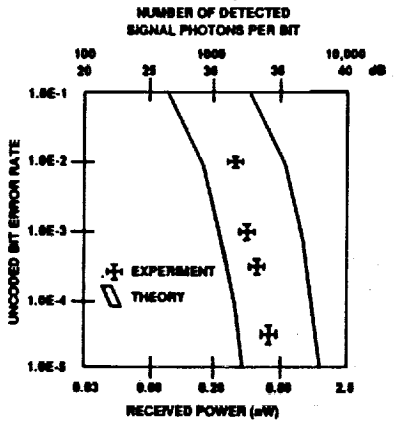


FIGURE 2. SCHEMATIC OF OPTICAL LINK DEMONSTRATION



JPL

SCOPE (SMALL COMMUNICATIONS OPTICAL PACKAGE EXPERIMENT) BREADBOARD

THE OBJECTIVE OF THIS TASK IS TO DEMONSTRATE THE FEASIBILITY OF DEVELOPING AN EXTREMELY SIMPLE AND LIGHT-WEIGHT OPTICAL COMMUNICATIONS PACKAGE FOR POSSIBLE SPACE DEMONSTRATIONS OF THE TECHNOLOGY IN THE FUTURE. THE APPROACH WAS TO DEVELOP A BREADBOARD FOR A SMALL COMMUNICATIONS OPTICAL PACKAGE EXPERIMENT (SCOPE). TO KEEP THE MASS OF SCOPE AS LOW AS POSSIBLE, A VERY SIMPLE SYSTEM WAS DESIGNED. WHEN SCOPE IS POINTED TOWARD A LASER BEACON, THE SCOPE TRACKING DETECTOR WILL LOCATE THE BEACON AND COMMAND A TWO-AXIS STEERING MIRROR TO ALIGN THE INCOMING BEACON LIGHT WITH THE TRANSMIT OPTICAL AXIS. THE INTENSITY-MODULATED OUTPUT OF THE SCOPE LASER DIODE IS THEN GUARANTEED TO POINT BACK IN THE DIRECTION OF THE BEACON. THE SCOPE TRANSMIT/RECEIVE APERTURE IS ONLY 1-CM IN DIAMETER, THUS PRODUCING A RELATIVELY BROAD BEAM IN THE FAR FIELD AND REDUCING THE REQUIREMENTS ON BEAM POINTING ACCURACY. THE ENTIRE SCOPE PACKAGE HAS A MASS OF LESS THAN 5KG.

THE SCOPE BREADBOARD LINK PERFORMANCE HAS BEEN CHARACTERIZED AT 1 MBPS WITH BINARY PULSE-POSITION MODULATION. AN AVALANCHE PHOTODIODE DETECTOR (APD) AND POST-DETECTION CIRCUITRY WERE ASSEMBLED AND USED TO MEASURE THE PERFORMANCE OF THE OPTICAL COMMUNICATIONS LINK. MEASUREMENTS OF BIT ERROR RATE AS A FUNCTION OF RECEIVED POWER WERE MADE AND SHOWN TO AGREE WELL WITH THEORETICAL PREDICTIONS.

A PHOTOGRAPH OF THE SCOPE OPTICAL BREADBOARD AS WELL AS A SCHEMATIC DIAGRAM OF THE RECEPTION AND MEASUREMENT SYSTEM USED TO CHARACTERIZE LINK PERFORMANCE ARE SHOWN. ALSO SHOWN IS A GRAPH SHOWING THE THEORETICAL PERFORMANCE PREDICTIONS (WITH PREDICTION UNCERTAINTIES DUE TO COMPONENT TOLERANCES) AND THE CORRESPONDING EXPERIMENTAL MEASUREMENTS WITH THEIR MEASUREMENT UNCERTAINTIES.

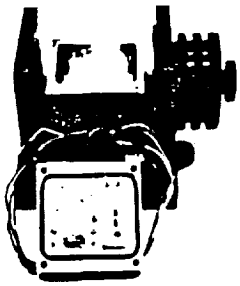
SCOPE IS AN INEXPENSIVE DEVELOPMENT ACTIVITY TO SERVE AS A PATHFINDER TO MORE CAPABLE OPTICAL TRANSCEIVER DEVELOPMENTS OF THE FUTURE.

TECHNICAL CONTACT: J. R. LESH, FTS 792-2766

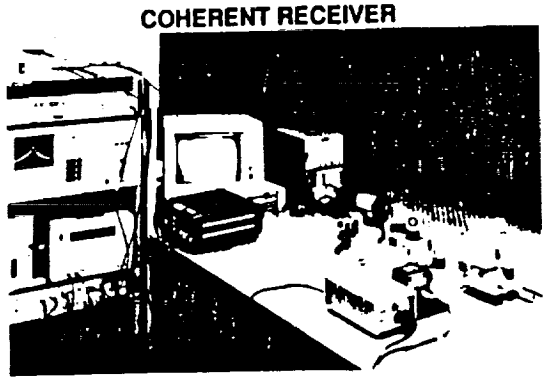
JPL

COHERENT OPTICAL LINK DEMONSTRATIONS

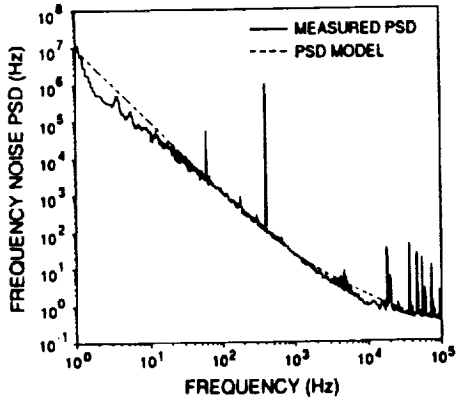
FREQUENCY STABILIZED LASER



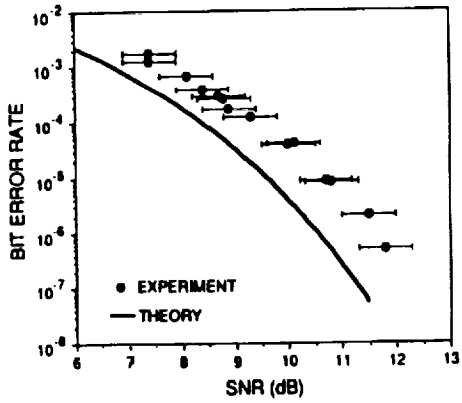
COHERENT RECEIVER



LASER FREQUENCY NOISE SPECTRUM



DEMO LINK PERFORMANCE



JPL

COHERENT OPTICAL COMMUNICATION LINK DEMONSTRATION

THE OBJECTIVE OF THIS TASK IS TO DEVELOP COHERENT OPTICAL RECEPTION TECHNOLOGIES THAT WILL ENHANCE THE PERFORMANCE OF OPTICAL COMMUNICATION SYSTEMS. COHERENT OPTICAL RECEPTION CAN OFFER 10-15 dB IMPROVEMENT IN RECEIVER SENSITIVITY AND A SIGNIFICANTLY IMPROVED BACKGROUND REJECTION CAPABILITY. SYSTEMS USING THE COHERENT RECEPTION TECHNOLOGY CAN POTENTIALLY COMMUNICATION WITH THE SUN IN THE FIELD OF VIEW. THE EFFICIENT SPECTRUM USAGE OF A COHERENT LINK CAN ALSO ALLOW MULTIPLE-ACCESS COMMUNICATION OVER A NARROW LASING LINE.

A CRITICAL ELEMENT IN ACHIEVING COHERENT RECEPTION IS A FREQUENCY STABLE OSCILLATOR. RECENT DEVELOPMENTS IN DIODE-PUMPED SOLID STATE LASER TECHNOLOGY HAVE RESULTED IN LASERS WITH SUB-KHZ FREE-RUNNING LINEWIDTH. ONE SUCH LASER IS THE NON-PLANAR RING OSCILLATOR LASER DEVELOPED BY LIGHTWAVE ELECTRONICS INC. UNDER A NASA SBIR. THE FREQUENCY NOISE SPECTRUM OF THIS LASER WAS MEASURED USING AN IF FREQUENCY DISCRIMINATOR AFTER HETERODYNE DETECTING THE BEAT SIGNAL BETWEEN TWO LASERS. THE ATTACHED FIGURE SHOWS THAT THE LASER FREQUENCY NOISE SPECTRUM CONSISTS LARGELY OF 1/F AND $1/F^2$ NOISES, WHEREAS THE WHITE FREQUENCY NOISE COMPONENT IS NEAR THE THEORETICAL SCHALOW-TOWNES LIMIT. THE LOW FREQUENCY NOISE IMPLIES THAT A PHASE COHERENT LINK CAN BE IMPLEMENTED AT A MUCH LOWER POWER THAN PREVIOUSLY ACHIEVABLE USING SEMICONDUCTOR LASERS.

A COHERENT OPTICAL COMMUNICATIONS LINK BASED ON THE FREQUENCY STABILIZED SOLID STATE LASER WAS IMPLEMENTED. THE LINK OPERATED AT 100 KBPS USING BINARY PULSE POSITION MODULATION. PHASE COHERENT RECEPTION WAS ACHIEVED WITH LESS THAN 10 PW OF RECEIVED OPTICAL POWER. THE PERFORMANCE OF THE LINK WAS CHARACTERIZED AND SHOWN TO PERFORM WITHIN 1±0.5 dB OF PROJECTION.

TECHNICAL CONTACT: J. R. LESH, FTS 792-2766

OPTICAL COMMUNICATION FLIGHT SYSTEM DEVELOPMENT

RC OAET

R&T SCOPE

Develop flight-like high data rate system to demonstrate technological maturity and readiness for space flight usage.

- 650 Mbps, duplex
- 1 microradian pointing
- 20 cm optics
- 250 lbs, 200 Watts

PAYOFFS

Improve performance of satellite communication systems by:

- Reducing size, weight and power
- Eliminating risk of antenna deployment, unfurlment
- Increasing data rate capability
- Eliminating issues of frequency allocation, crowding

BENEFITS

Reductions in communication system size, weight, and power will enable more advanced sensors to be accommodated onboard spacecraft. Increases in data rate capability will permit operation by higher resolution multi-spectral imagers and synthetic aperture radars (EOS). Will expand coverage of NASA data relay system (ATDRSS) using GEO x-links.

TECHNICAL CHALLENGE

- High accuracy pointing
- High power, reliable lasers
- Sensitive, wideband receivers
- Low power, wideband electronics

OPTICAL COMMUNICATION FLIGHT SYSTEM DEVELOPMENT

RC OAET

APPROVED BUDGET	FY91	FY92	FY93	FY94	FY95
GSFC (K$)	2000	2170	2200	2250	2300

MAJOR MILESTONES

FY 1991	System preliminary design complete
FY 1992	System final design complete
FY 1993	Subsystem fabrication and assembly
FY 1994	System integration
FY 1995	System testing and evaluation complete meeting the following requirements:

System design requirements
- 650 Mbps, duplex
- 1.2 Watt laser transmitter using power summing
- 50 photon/bit sensitivity at 10^{-6} ber
- 1 microradian pointing

AGENCY THRUST Primary: Operations/Near earth space communication
Secondary: Space exploration

CENTERS GSFC, LeRC, LaRC

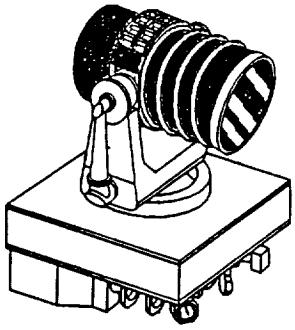
ADEQUACY OF RESOURCES

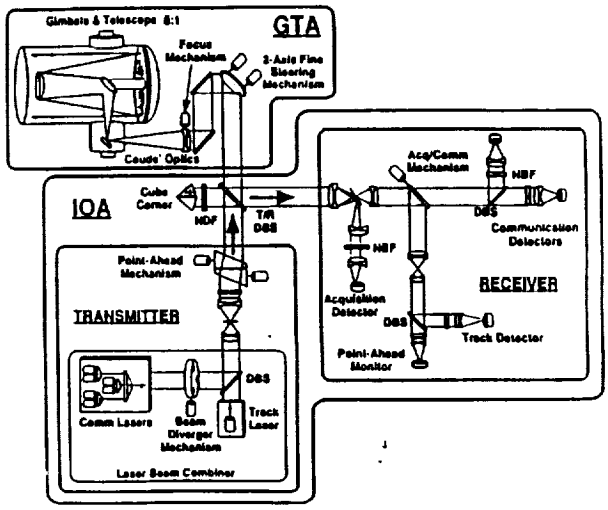
Existing resource level is adequate to complete ground test programs. Program and key personnel have world-wide recognition.

CURRENT STATUS Current technology readiness level: 4

Flight Systems Development and Demonstration Program

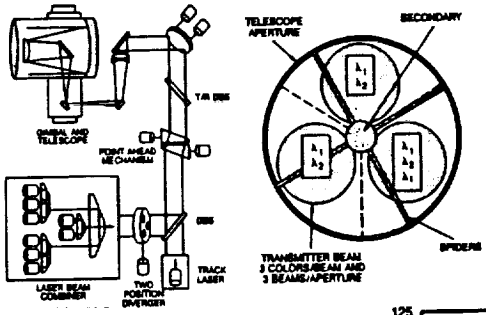
Data Rate:	650 MBPS, Duplex
Data Quality:	10^{-6} BEP, Uncoded
Laser Type:	Semiconductor, Al GaAs
Modulation:	4 Slot PPM
Receiver:	Direct Detection
Telescope:	8 Inch Dia
Range:	21,000 Km
Weight:	< 250 lbs
Power:	< 200 Watts

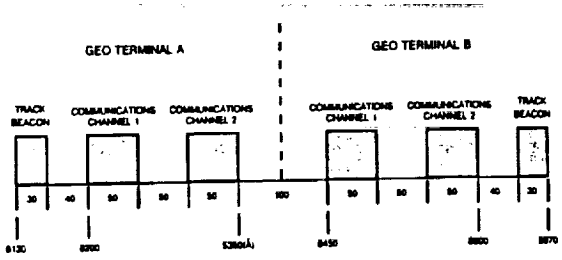




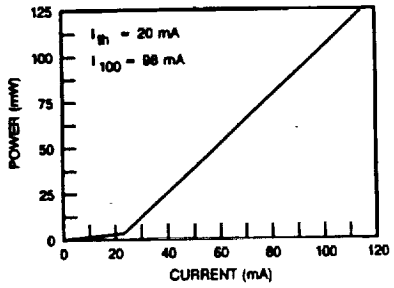
TRANSMITTER CONFIGURATION

- THE LASER BEAM COMBINER IS A HYBRID OF SPATIAL & DICHROIC TECHNIQUES
- THIS REDUCES THE PERFORMANCE REQUIREMENTS ON BOTH THE POINTING SYSTEM & THE LASER WAVELENGTH STABILITY





SYSTEM WAVELENGTH ALLOCATION



LASER PERFORMANCE (25°C)

F350.002

GSFC Flight Systems Development and Demonstration (FSDD) Program

The FSDD program will produce a high performance optical communication terminal which is designed in a "flight-like" configuration. This system will not be flight qualified, but will utilize designs and technologies which can easily be extended to full flight qualification.

The system concept is based on a 650 MBPS duplex communication crosslink between geosynchronous satellites. Such links are being considered by NASA to extend the coverage of its Advanced Tracking and Data Relay Satellite System (ATDRSS). Potential usage of such links for commercial communication (e.g., INTELSAT) are also being investigated. The FSDD system configuration is quite versatile and is equally applicable to a low earth orbit spacecraft.

The baseline design is relatively conservative; it is based on proven subsystem approaches and readily available technologies. Key technical aspects of the system include silicon avalanche photodiode direct detection receivers, 4 slot pulse position modulation, and high efficiency AlGaAs semiconductor laser transmitters. The high speed digital electronics required on both the transmit and receive paths are a significant part of the development effort; ASIC implementations will be utilized to achieve the high bandwidth while keeping power dissipation to a minimum.

After completion of the fabrication, assembly, and integration phases, the FSDD system will go through a comprehensive ground test program. These tests will quantify the performance levels which can be achieved with currently available technology, and will serve to verify the methodologies and analytical models used to design spaceflight optical communication systems. In the future, significant performance improvements can be expected in both transmitter and receiver technologies. Current lasers operate reliable with output powers of about 0.1 watts. A factor of 10 increase is likely within 2-3 years. Receiver sensitivity is currently in the 60-80 photons/bit range. A factor of 2 improvement is likely within 1-2 years and additional improvement will ultimately be achieved using heterodyne receivers. With development activities continuing aggressively in the USA, Japan, and Europe, future systems will certainly have even higher performance capabilities with reduced weight, size, and power burdens on the host spacecraft.

Technical Contacts: Michael Fitzmaurice, GSFC, (301) 286-8006
David Nace, GSFC, (301) 286-7023

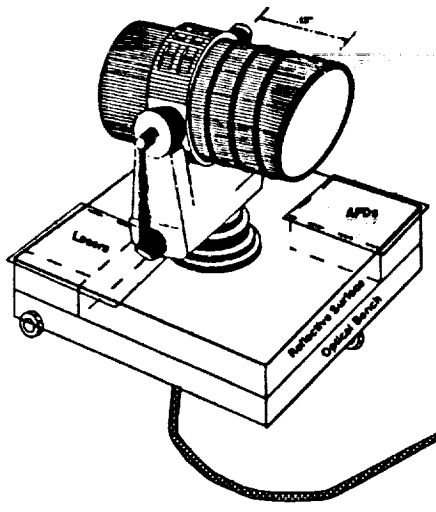
AEROSPACE TECHNOLOGIES

NASA
Lewis Research Center

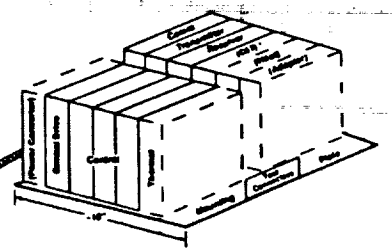
High-speed Laser Integrated Terminal Electronics (Hi-LITE) Project

- **Communications electronics subsystem for NASA Goddard optical communications demonstration testbed**
- **325/650 Mbps quaternary pulse-position modulation (QPPM) and demodulation**
- **Computer controlled custom test equipment including optical link effects simulation and high resolution digital video transmission**

Optical Transceiver Assembly



Electronics Assembly



For several years NASA Goddard Space Flight Center has conducted an optical communications program to demonstrate the potential of laser transmitters and receivers for high data rate intersatellite link applications. A few years ago, Goddard sponsored the development of a Direct Detection Laser Transceiver at TRW which was slated to fly on the ACTS. More recently, their proposal for an optical communications package had been selected as a Space Station attached payloads experiment. To avoid the cost impact of contracted development, and leverage off Lewis' expertise in high-speed electronics and space communications hardware, Goddard turned to the Space Electronics Division (SED) at Lewis for development of the communications electronics subsystem for their optical communications program.

In late 1989 Dr. Michael Fitzmaurice, Assistant Chief for Communications Programs in the Instrument Division at Goddard, requested that the SED design and develop two 650 Megabit per second "modems" for their Flight System Development and Demonstration (FSDD) Project. In March 1990 SED established a task team to develop conceptual designs and alternative approaches, make technical recommendations, and estimate the funding, schedule, labor requirements for an in-house development. The task team's findings and a project plan were presented to and accepted by Goddard in May 1990. The conceptual designs served as the basis for the Hi-LITE Project whose purpose is to develop the communications electronics subsystems hardware, the ground support equipment and controlling software, and the necessary special test equipment for inclusion into the FSDD testbed.

The Hi-LITE Project team is developing two versions of a quaternary pulse-position modulation (QPPM) modem. The first one, designed and fabricated completely in-house, will use discrete digital and analog integrated circuits to demonstrate functional performance. The second one, designed in-house but fabricated under contract, will be implemented as a semi-custom digital chip and an analog hybrid module to demonstrate flight-qualifyability. The two modems will allow duplex communications at 650 Mbps between Goddard's two optical transceivers. Hi-LITE also includes the development of test data sources at 325 and 650 Mbps, digitized high-resolution video equipment, optical link effects simulation, and computer control experimentation and data collection. The Hi-LITE Project team successfully completed a preliminary design review in November 1990. A critical design review of the flight-like version is scheduled for August 1991. Delivery and acceptance testing at Goddard is scheduled for January 1993.

The viewgraph depicts a possible flight-like configuration of the optical transceiver consisting of the laser transmitters, telescope, and optical detectors, and the electronics assembly consisting of modules for pointing, tracking, control, and communications.

NASA Lewis Technical Contact: James M. Budinger (216) 433-3496

RC **COMMUNICATIONS PROGRAM** OAET

Systems Integration, Test and Evaluation

SYSTEMS INTEGRATION, TEST AND EVALUATION

RC — OAET

R&T SCOPE

Develop, maintain, and operate a Satellite Communication System Simulator and Testbed for system experimentation, component and subsystem development and testing, and network development and demonstration

PAYOFFS

Demonstrate advanced components, subsystems and network architectures for current and future space communications systems. Test and evaluate components and subsystems for NASA and industry space operations and commercial programs. Evaluate effects of atmospheric and propagation disturbances, interference, noise non-linearities, satellite motion and hardware and system imperfections on system performance.

BENEFITS

Enable new and innovative space communications systems and services. Unique national facility for system, subsystem, and component evaluation available to NASA and industry.

TECHNICAL CHALLENGE

Maintain and expand state-of-the-art system simulator and testbed. Identify, develop, test, evaluate, and demonstrate advanced components, subsystems, and network concepts.

SYSTEMS INTEGRATION, TEST AND EVALUATION

RC — OAET

APPROVED BUDGET	FY91	FY92	FY93	FY94	FY95
LeRC (K$)	900	950	1000	1100	1200

MAJOR MILESTONES

FY 1991 Complete development of Phase II SS-TDMA network
Perform single terminal network experiments

FY 1992 Perform two- and three-terminal network experiments
Define testbed requirements for 60 GHz intersatellite link system

FY 1993 HBR-INTEX ACTS experiment
Intersatellite link hardware development and integration

AGENCY THRUST Primary: Operations
Secondary: Exploration/science

CENTERS LeRC **MISSION** Commercial communication, ACTS, ATDRSS, Lunar/Mars exploration

ADEQUACY OF RESOURCES

Unique simulation and test bed facility. Excellent results obtained. Funding level inadequate for continued facility upgrading, maintenance and expansion.

CURRENT STATUS

Phase II SS-TDMA Network Experiments Program in progress.
Development of concepts, components, subsystems continues.

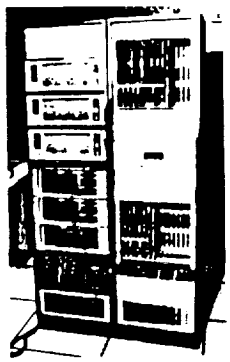
NASA
C-88-04108

AEROSPACE TECHNOLOGY DIRECTORATE

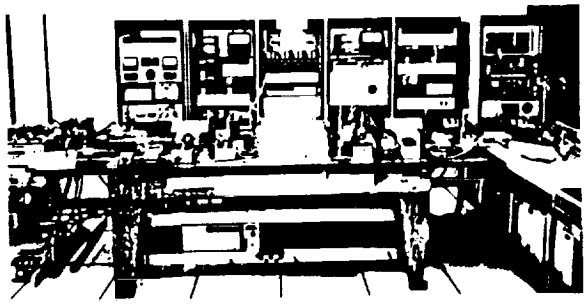
SPACE ELECTRONICS DIVISION

NASA Lewis Research Center

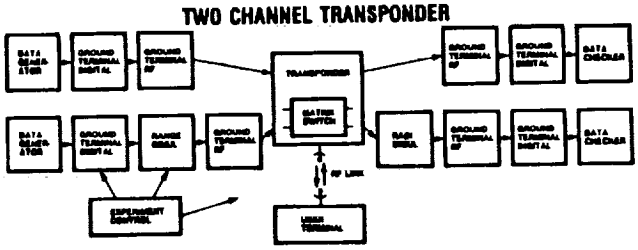
SITE MULTI TERMINAL NETWORK SIMULATION



GROUND TERMINAL DIGITAL



TWO CHANNEL TRANSPONDER



CD-88-34583

SYSTEMS INTEGRATION, TEST AND EVALUATION

NASA Lewis Research Center

The Systems Integration, Test and Evaluation (SITE) Project provides a system-level capability for development and evaluation of advanced space communication systems, networks, components, and subsystems.

The SITE space communication system laboratory includes microwave instrumentation, computer control and monitoring, and digital and microwave circuit and subsystem development and testing. The major feature of the facility is a Satellite Communication System Simulator and Testbed. The simulator allows satellite system experimentation, the testing and evaluation of components and subsystems, and the development and demonstration of network architectures. The simulator is developed through both in-house and contracutal component and subsystems developments.

The SITE System Simulator is currently configured as a three terminal satellite switched TDMA network, including three variable rate digital burst ground terminals, a three channel Ka-Band transponder, network control computer, experiment control and monitor computer, and a radiative 30/20 GHz RF link to a remote terminal. The Phase II SS-TDMA Network Experiments Program will demonstrate the operational capabilities of such a system and investigate the effects of satellite range variation and doppler, interference, noise, rain fade and compensation, amplitude and phase distortions, and system synchronization. The capability of the SITE facility in this regard is unique.

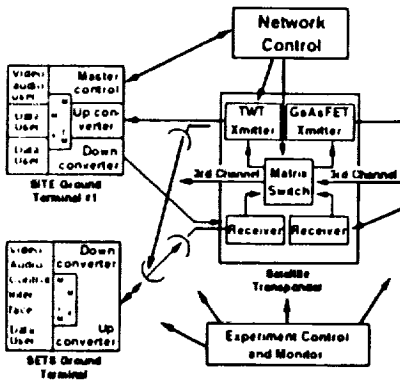
Currently, the Phase II Network Experiment Program is well under way. Extensive use of SITE's capabilities will also be made for the ACTS interference experiment (HBR-INTEX). The next phases of the SITE simulator system development are now being planned, and include an intersatellite link network test, experimentation and demonstration capability, development of a test ground terminal capable of variable data rates, modulations, and coding formats, an enhancement of the system commercial digital interfaces, and upgrading of the microwave circuit development capability.

The SITE facility has been used to obtain an extensive set of data on the performance of a Ka-Band system transmitting continuous high rate data under a variety of noise, distortions, and interference scenarios. Several components and system concepts have been tested in support of the ACTS program, and SITE facilities and expertise have been used in the development of ACTS' High Burst Rate Link Evaluation Terminal (HBR-LET) and the ATDRSS Digital Beamforming System. Milestones completed in the Phase II Program include the completion of the SITE multi-channel transponder, completion and testing of two ground terminals, the transmission of multiple channel bursted data, including video and audio data, and ground terminal acquisition and synchronization with the satellite matrix switch.

Technical contact: Robert J. Kerczewski, LeRC, (216) 433-3434 (FTS 297-3434)
William D. Ivancic, LeRC, (216) 433-3494

SITE MULTI-TERMINAL NETWORK EXPERIMENTS

NASA Lewis Research Center



Satellite-Switched TDMA Network Demonstration

A series of experiments using one, two, and three TDMA ground terminals, in a satellite-switched TDMA network.
Switching between two or three "ACTS-type" spot beams

Experimental Parameters

Satellite range delay, range variation, and doppler shift and their effect on system synchronization
Rain fade and compensation techniques
Co and adjacent channel interference
Noise, non-linearities, and equalization
System and hardware imperfections
Performance of different hardware, subsystems, and network algorithm

Network Simulation Facility Features

30GHz low noise receivers
Hybrid and MMIC microwave matrix switches
20 and 30 GHz solid state and TWT power amplifiers
High rate (220 MBPS) burst modems
On-board processing hardware
Three-channel 30/20 GHz satellite transponder
Digital TDMA multi-data-rate ground terminals
Digital video/audio interfaces
Transponder configuration control
Network control algorithms and implementation
Automated experiment control, data display & analysis
Range delay and rain fade simulation hardware
30/20 GHz radiative SITE-SETS link to remote terminal

CD-91-58418

SYSTEMS INTEGRATION, TEST AND EVALUATION

NASA Lewis Research Center

SITE MULTI-TERMINAL NETWORK EXPERIMENTS

The SITE Multi-Terminal Networks Experiments will use the SITE Satellite Communication System Simulator to perform a series of experiments to demonstrate and evaluate technologies required for satellite-switched multiple access networks.

Three digital TDMA ground terminals and a three-channel 30/20 GHz transponder with an IF matrix switch,have been developed for use in these experiments. These ground terminals provide an MSK modulated signal at 220 Mbps at a number of data throughput rates. With this hardware, a network simulation which is adequate for testing all of the major parameters has been created. The network demonstrates the use of an ACTS MSM mode type of operation through a satellite-based microwave matrix switch. Such a network allows many users to access the satellite in the same frequency band simultaneously by using small geographically isolated antenna spot beams. These beams are then interconnected through the matrix switch in any fashion required by the network traffic. In addition to evaluating the performance of the satellite transponder components (receivers, transmitters, matrix switches) under such conditions, several important system aspects must be proven. Most important is the network synchronization. With the satellite moving around slightly in orbit, the effect is for each ground terminal to see a different satellite range, range variation, and doppler shift. Each ground terminal must be able to keep in synchronization with the network independently, and the network control must synchronize and monitor the entire network of ground terminals. Lewis has developed range delay hardware capable of simulating all of the effects at various ranges and rates.

Also to be included in the network experiments are the effects of rain fade and compensation techniques, co-channel and adjacent channel interference, noise, non-linearities and equalization. In addition, the experiments will also use the SITE-SETS radiative link to a remote ground terminal.

The network experiments will be done in three sets. In the first set, a single "master control" ground terminal will be used to evaluate acquisition, tracking, and synchronization in the presence of satellite range variation, rain fade, and interference. In the second set, a second "traffic terminal" will request access to the network, and the more difficult network synchronization experiments will take place, again in the presence of various impairments. The third set of tests will exercise a three ground terminal network. First, a co-channel environment will be simulated where two ground terminals reside in the same spot beam (using the SITE-SETS link). Finally, the three ground terminals will reside in three separate spot beams, requiring full 3 X 3 dynamic switching of the satellite matrix switch.

Technical contact: William D. Ivancic, LeRC (216) 433-3494 (FTS 297-3494), Robert J. Kerczewski, LeRC (216) 433-3434

RC

GROUND TERMINAL DEVELOPMENT

OAET

R&T SCOPE

Develop a high burst rate link evaluation terminal (LET) and a mini terminal test bed (MTTB) for use with the ACTS satellite. The LET plus the MTTB provide both halves of multi application full duplex communications link.

PAYOFFS

Demonstration of multibeam systems and ground terminal technology at Ka-band

BENEFITS

LET	Enables ACTS communications experiments in the multibeam switch matrix mode and with adaptive uplink power augmentation
	Enables ACTS technology characterization tests
MTTB	Provides a small, low-cost, ground terminal for experimentation with the ACTS spacecraft

TECHNICAL CHALLENGE

LET	Adaptive uplink power control, 220 Mbps burst rate
MTTB	Prove that a low cost ground terminal can be built for use with the ACTS spacecraft

RC

GROUND TERMINAL DEVELOPMENT

OAET

APPROVED BUDGET LeRC (K$)

	FY91	FY92	FY93	FY94	FY95
ACTS link evaluation terminal (LET)	237* 20	86* 10			
Ka-band mini terminal test bed (MTTB)		140	150	150	50

* ACTS funded

MAJOR MILESTONES

LET -	FY 1991	Stand-alone systems test complete
	FY 1992	Testing with ACTS S/C at GE
MTTB-	FY 1992	System design complete
	FY 1993	Detailed design complete, start development
	FY 1994	Complete development and initiate testing
	FY 1995	Complete tests using ACTS

AGENCY THRUST Primary: Operations
Secondary: Exploration

CENTERS LeRC **MISSION** ACTS, Commercial Communications

ADEQUACY OF RESOURCES

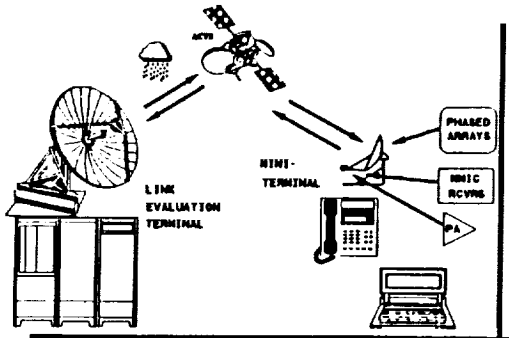
Highly experienced LeRC team is meeting program goals and milestones

CURRENT STATUS LET - Technology readiness level: 6
MTTB - Technology readiness level: 2

AEROSPACE TECHNOLOGY DIRECTORATE

GROUND TERMINAL DEVELOPMENT

NASA Lewis Research Center



OBJECTIVES

LINK EVALUATION TERMINAL

- DEMONSTRATE 200 MBPS DATA LINK
- BURSTED BER MEASUREMENTS
- ADAPTIVE UPLINK POWER CONTROL

MINI-TERMINAL

- TEST BED FOR:
  - MMIC RECEIVERS
  - POWER AMPLIFIERS
  - ACTIVE & PASSIVE PHASED ARRAY ANTENNAS
- DEMONSTRATE LOW COST, LOW DATA RATE TERMINALS

BENEFITS

LINK EVALUATION TERMINAL

- ENABLES COMMUNICATIONS EXPERIMENTS THROUGH MICROWAVE SWITCH MODE
- ENABLES ACTS TECHNOLOGY TESTS

MINI-TERMINAL

- DEMONSTRATES LOW COST TERMINAL FOR:
  - ALPHANUMERIC COMMUNICATIONS
  - TELEPHONE COMMUNICATIONS
- TEST BED FOR LERC-DEVELOPED COMPONENTS

ACCOMPLISHMENTS

LINK EVALUATION TERMINAL

- PDR	NOV 87
- CDR	APR 90
- BURSTED DATA TEST	APR 91

(FIRST TRANSMISSION THRU LOOPBACK)

- FINAL TESTING IN PROGRESS

MINI-TERMINAL

PRELIMINARY PLANNING AND ANALYSIS COMPLETED

VHD02591

AEROSPACE TECHNOLOGY DIRECTORATE

GROUND TERMINAL DEVELOPMENT

NASA Lewis Research Center

HIGH BURST RATE LINK EVALUATION TERMINAL (LET)

THE OBJECTIVE OF THE LINK EVALUATION TERMINAL EFFORT IS TO DEVELOP A GROUND TERMINAL THAT WILL ENABLE CHARACTERIZATION OF THE MULTIBEAM COMMUNICATIONS PACKAGE ON THE ACTS SPACECRAFT AND PROVIDE A VERSATILE FACILITY FOR EXPERIMENTERS.

THE HIGH BURST RATE LINK EVALUATION TERMINAL (LET) IS A PROTOTYPE GROUND STATION BEING DEVELOPED TO SUPPORT ADVANCED COMMUNICATIONS TECHNOLOGY SATELLITE (ACTS) EXPERIMENTS. A TEAM LED BY THE SPACE ELECTRONICS DIVISION HAS DESIGNED AND DEVELOPED A FIRST-OF-A-KIND GROUND TERMINAL OPERATING IN THE 30/20 GHz BAND, TO BE USED FOR EXPERIMENTS REQUIRING HIGH DATA RATES, SUCH AS COMPUTER-TO-COMPUTER COMMUNICATIONS. THE LET WILL SUPPORT A VARIETY OF EXPERIMENTS CONDUCTED BY UNIVERSITIES, GOVERNMENT AND INDUSTRY DURING A TWO-YEAR PERIOD AFTER ACTS IS LAUNCHED AND DEPLOYED. THE TERMINAL IS DESIGNED TO MEASURE THE BIT ERROR RATE WHEN OPERATED AT BURST RATES OF 110 AND 220 MEGABITS PER SECOND AND WILL TEST UPLINK POWER CONTROL METHODS DURING FADING SIGNAL (RAINY) CONDITIONS. THE LET IS CURRENTLY IN THE SYSTEM INTEGRATION AND TESTING STAGE. AFTER TESTING IS COMPLETED THE TERMINAL WILL BE SHIPPED TO GE's ASTRO-SPACE FACILITY IN PRINCETON, NJ FOR GROUND TESTING WITH THE ACTS SPACECRAFT IN THE SUMMER OF 1992.

MINI TERMINAL TEST BED (MTTB)

THE OBJECTIVE OF THE MINI TERMINAL TEST BED IS TO PROVIDE THE CAPABILITY OF TESTING AND EVALUATING NUMEROUS VARIATIONS OF UPLINK POWER, ANTENNAS, MMIC PREAMPS, RECEIVERS, MODEMS AND CODECS. THIS TEST AND EVALUATION IS DONE WITH COMPONENTS THAT HAVE A HERITAGE IN THE MILITARY OR COMMERCIAL ARENAS. FOR MANY OF THE COMPONENTS, THE FUNDAMENTAL RESEARCH AND DEVELOPMENT HAVE ALREADY BEEN ACCOMPLISHED. THIS LEADS TO LOW TEST BED COST. SINCE THE TEST AND EVALUATION IS PERFORMED WITH LOW COST ELEMENTS, DEMONSTRATIONS WILL SHOW THAT SPACE COMMUNICATIONS CAN BE PERFORMED AT COSTS THAT ARE NOT BURDENSOME.

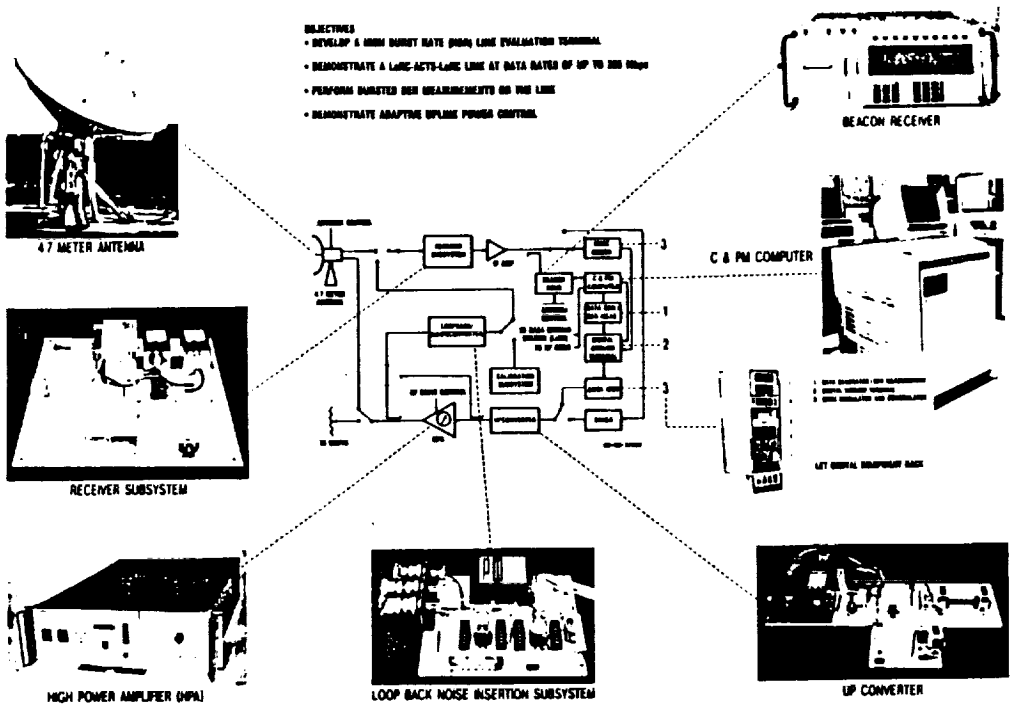
THE MTTB WILL BE THE SECOND HALF OF A FULL DUPLEX SPACECRAFT TELEPHONE AND ALPHA-NUMERIC COMMUNICATIONS SYSTEM, WITH THE LET TERMINAL AS THE FIRST HALF. THE MTTB WILL HAVE AN INITIAL ANTENNA SIZE OF 2' (0.6 M). THE INITIAL MTTB ANTENNA WILL CONSIST OF A REFLECTOR AND PEDESTAL THAT HAS BEEN DEVELOPED FOR COMMERCIAL USE. THE 30/20 GHZ FEED HAS BEEN DEVELOPED FOR ACTS LBR-2 TERMINAL USE. THE CODEC IS A UNIT THAT HAS BEEN DEVELOPED BY THE MILITARY, AND IS JUST BEGINNING TO BE MARKETED COMMERCIALLY. OTHER ELEMENTS OF THE MTTB WILL BE DESIGNED WITH COMMERCIALLY AVAILABLE COMPONENTS.

THE MTTB WILL BE USED TO TEST COMPONENTS AND TECHNIQUES THAT HAVE BEEN DEVELOPED IN HOUSE, AND TO TEST THE ABILITY OF COMMERCIAL COMPONENTS AND ENCODING CONCEPTS IN OVERCOMING THE EFFECTS OF LINK DEGRADATIONS. THE MTTB WILL PROVIDE THESE TEST RESULTS IN A SMALL TERMINAL ENVIRONMENT WHICH WILL DRAMATICALLY DEMONSTRATE THAT LARGE EARTH TERMINALS ARE NOT NEEDED FOR MANY COMMUNICATIONS APPLICATIONS.

TECHNICAL CONTACTS: LET: GERALD J. CHOMOS, LeRC, (216) 433-3485 MTTB: MARTIN J. CONROY, LeRC, (216) 433-3449

NASA
C-91-08168

HIGH-BURST RATE LINK EVALUATION TERMINAL FOR ACTS SATELLITE



RC

COMMUNICATIONS PROGRAM

OAET

Mobile Communications Technology

ACTS MOBILE SATELLITE COMMUNICATIONS TECHNOLOGY PROGRAM

RC OAET

R&T SCOPE

Component, subsystem and system development for future Ka-band mobile and personal satellite communication systems

PAYOFFS

Significantly more bandwidth for communications available at Ka-band, allowing higher throughput systems; smaller and lighter RF system components, providing smaller user terminals

BENEFITS

Develops the enabling, high risk technologies, system components and performs the field experiments required for a future commercial personal/mobile satellite communication system.

TECHNICAL CHALLENGE

- Tracking high gain vehicular antennas
- Power efficient, fade tolerant communications
- Compensating for high rain attenuation
- Correcting for large Doppler shifts and frequency offsets

ACTS MOBILE SATELLITE COMMUNICATIONS TECHNOLOGY PROGRAM

RC OAET

APPROVED BUDGET	FY91	FY92	FY93	FY94	FY95
JPL (K$)	3400	3300	3300	3000	1300

MAJOR MILESTONES

FY 1991	PDR, CDR system design completed
FY 1992	Multirate modem, reflector antenna (22 dBi gain, -7.6 dBK G/T)
FY 1993	Van experiments, active antenna (22 dBW EIRP, -8 dBK G/T)
FY 1994	Experiments using active array antenna & automobile

AGENCY THRUST Primary: Operations

CENTERS JPL **MISSION** Commercial satellite communications

ADEQUACY OF RESOURCES

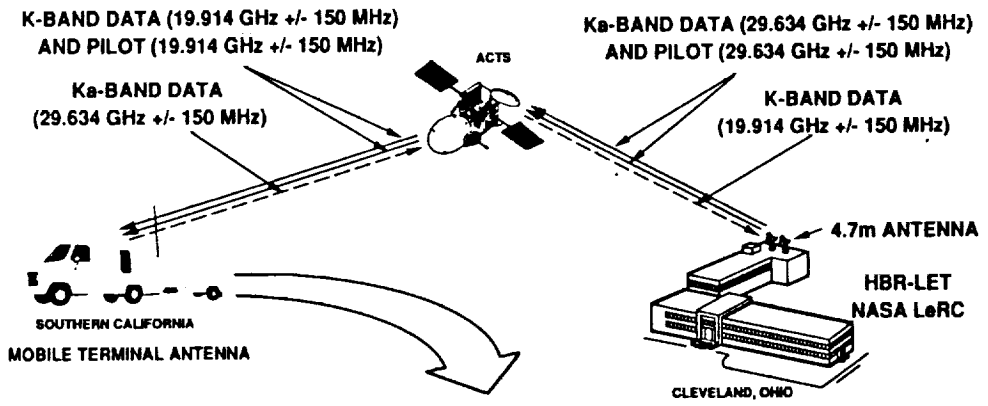
Good resources throughout the program, except that an additional $690K is required for FY94 to complete project plans. Excellent staff and facilities in place.

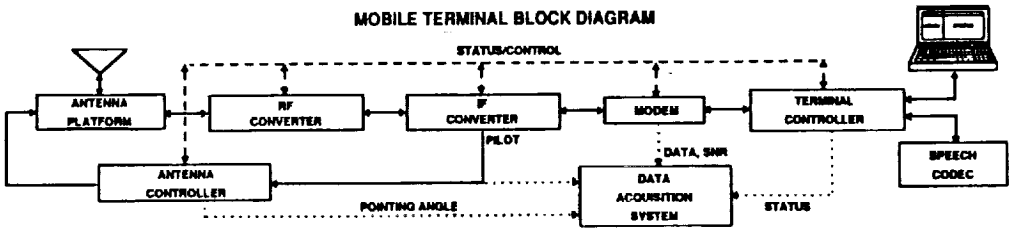
CURRENT STATUS Current technology readiness level: 2/4

JPL

ACTS MOBILE SATCOM TECHNOLOGY PROGRAM

- KA-BAND LAND-MOBILE COMMUNICATION SYSTEM AND TECHNOLOGY TESTBED
- BOTH FIXED AND MOBILE TERMINALS; SMALL, MEDIUM GAIN (22 dBi) ANTENNAS





ACTS MOBILE SATELLITE COMMUNICATIONS TECHNOLOGY PROGRAM EXPERIMENTAL SETUP

The figure is divided into two sections. A block diagram of the experimental setup showing the ACTS Mobile Terminal/Technology Testbed (AMT), located in Southern California, communicating through the Advanced Communications Technology Satellite (ACTS) with a fixed station, located at the High Bit Rate Link Evaluation Terminal (HBR-LET) at NASA LeRC, in Cleveland, Ohio. The arrow from the mobile terminal points to a block diagram of the AMT, where the major terminal components are shown.

The objective of the task is to design, develop, assemble, and test a full Ka-band land-mobile satellite communications system that utilizes ACTS for the space segment. The terminal, with the exception of the antennas, may be used in both the maritime and aeronautical environments with minimal redesign. The major terminal components are a mechanically steered reflector antenna, a mechanically steered active array antenna (MMIC LNA's and HPA's integrated onto the array), both antennas with approximately 12 elevation and 3 azimuth beamwidths, a transceiver (the IF and RF converters), a multirate modem (2.4, 4.8, 9.6, 64 kbps) and speech codec (2.4, 4.8, 9.6 kbps), a terminal controller for overall terminal control and user interface, and a data acquisition system for post experiment data analysis (terminal and propagation data).

The task is in the detailed design phase, and breadboards of the reflector antenna, IF and RF converters, modem, and speech codec are under development. The terminal controller and the data acquisition system are VME based systems, and software development for these systems is underway.

TECHNICAL CONTACT: Thomas C. Jedrey, JPL (818) 354-5187 OR FTS 792-5187

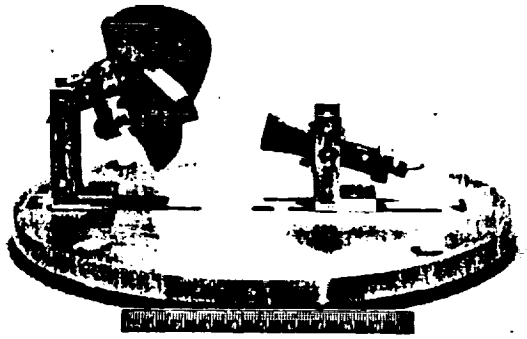
JPL

ACTS MOBILE SATCOM TECHNOLOGY PROGRAM

MOBILE TERMINAL ANTENNAS

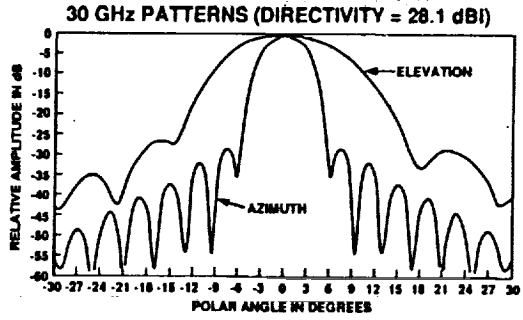
- MEDIUM GAIN (22 dBi), MECHANICALLY STEERED, SMALL REFLECTOR AND ACTIVE ARRAY UNDER DEVELOPMENT

REFLECTOR ANTENNA TESTBED

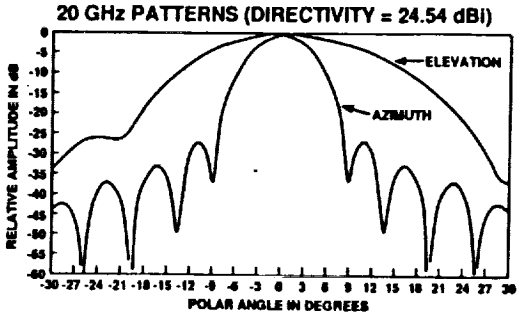


PREDICTED REFLECTOR ANTENNA PATTERNS

30 GHz PATTERNS (DIRECTIVITY = 28.1 dBi)



20 GHz PATTERNS (DIRECTIVITY = 24.54 dBi)



ACTS MOBILE SATELLITE COMMUNICATIONS TECHNOLOGY PROGRAM REFLECTOR ANTENNA

The figure is divided into two sections. A picture showing the small reflector testbed is on the left of the viewgraph, and plots showing the predicted antenna patterns are shown on the right of the viewgraph.

The reflector testbed consists of a prototype elliptical reflector, a calibrated 30 GHz feed horn, the platform on which the reflector and feed horn are mounted, and the mounts for the reflector and the feed horn. The reflector is a prototype of the AMT reflector and weighs approximately 3.5 ounces. The feed will be an offset feed. Other components (other than the feed and reflector) that will be on the actual antenna platform are a diplexer, and the rotary joint that connects through the rotating platform.

The predicted antenna patterns at 20 and 30 GHz are shown in two sets of plots. At 30 GHz, the computed directivity is 28.10 dBi, the elevation beamwidth is approximately 12 degrees and the azimuth beamwidth is approximately 3 degrees. The antenna is specified to have a minimum gain of 22 dBi at the +/- 6 degree points in the elevation pattern and the +/- 1.5 degree points in the azimuth pattern. At 20 GHz, the directivity is 24.54 dBi, the azimuth beamwidth is approximately 6 degrees, and the elevation beamwidth is approximately 18 degrees. The G/T is specified to be less than or equal to -8 dBK.

A prototype of the reflector has been constructed and pattern measurement using the testbed in the picture are being undertaken. The feed design has been completed and a work/procurement order to construct it is in process. Work is progressing on a active array as well.

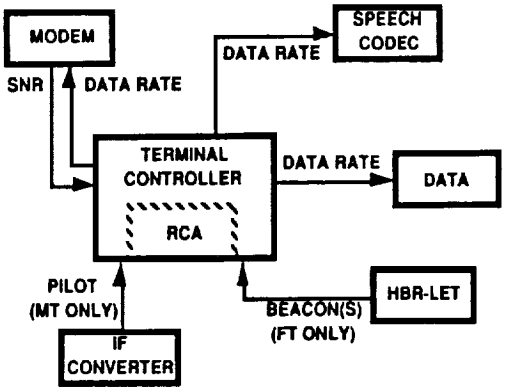
TECHNICAL CONTACT: Thomas C. Jedrey, JPL (818) 354-5187 OR FTS 792-5187

JPL

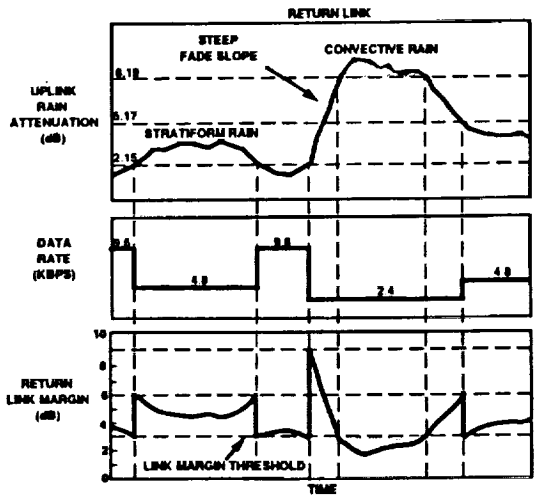
ACTS MOBILE SATCOM TECHNOLOGY PROGRAM TERMINAL CONTROLLER RCA/DRC ALGORITHM

- RCA/DRC OBJECTIVE: MAXIMIZE DATA RATES WHILE MAINTIAINING 3dB MINIMUM LINK MARGIN IN THE PRESENCE OF RAIN

RCA/DRC OPERATION



RCA/DRC EXAMPLE



ACTS MOBILE SATELLITE COMMUNICATIONS TECHNOLOGY PROGRAM TERMINAL CONTROLLER RCA/DRC ALGORITHM

The viewgraph is divided into two areas to illustrate the operation of the Rain Compensation Algorithm (RCA) and Data Rate Change (DRC) Algorithm in the terminal controller. The figure on the left hand side of the viewgraph illustrates the RCA/DRC operation in the terminal controller. The figure on the right hand side of the view graph illustrates the operation of the RCA/DRC on the return link (mobile to fixed terminal).

The RCA/DRC Algorithm is an approach that is being developed for use in the ACTS Mobile Terminal to combat the deleterious effects of rain at 20/30 GHz. In particular, the algorithms have been developed to maintain a voice/data link at the highest possible quality in the presence of rain fades. The basic idea behind the RCA/DRC is that both the Mobile Terminal (MT) and the Fixed Terminal (FT) have various types of information on the presence/absence of fades in their portions of the communications link. The types of information available ranges from received data based SNR measurements, to received pilot/beacon SNR measurements. Based on this information, the decision to increase/decrease the link data rate is made, providing either improved voice quality/higher data rate communications, or providing further link margin. An example of the operation of these algorithms is shown in the second figure, where the uplink rain attenuation for the return link is shown along with the data rate and the link margin. To illustrate the performance of this technique, using worst month rain attenuation statistics, it is estimated that the link availability in Los Angeles would increase to 99.7% from 97.2%, and in Portland, Maine, from 90.5% to 98.1%.

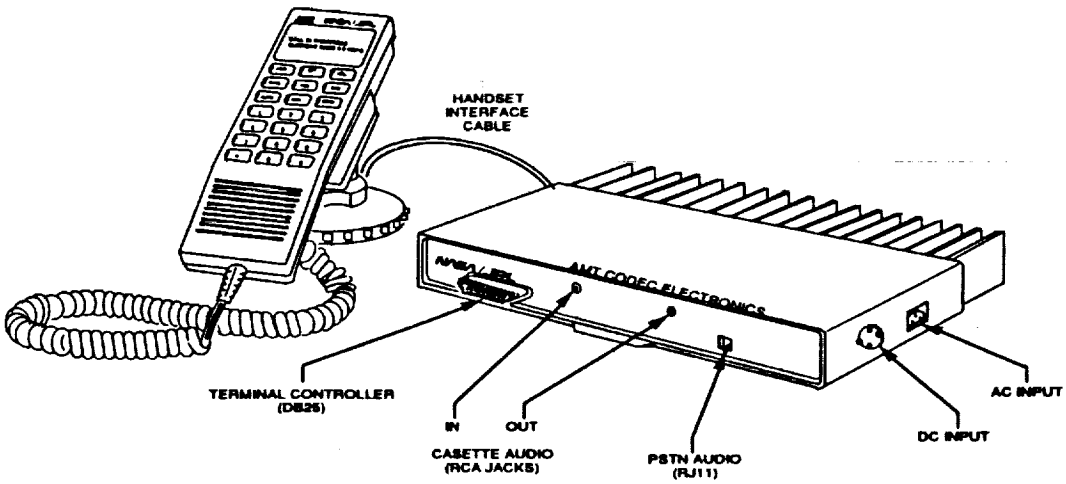
TECHNICAL CONTACT: Thomas C. Jedrey, JPL (818) 354-5187 OR FTS 792-5187

JPL

ACTS MOBILE SATCOM TECHNOLOGY PROGRAM MULTIRATE SPEECH CODEC

- MULTIRATE SPEECH CODEC - 2.4, 4.8, 9.6 KBPS COMPRESSED SPEECH
- USED IN CONJUNCTION WITH RAIN COMPENSATION ALGORITHM

CODEC CONFIGURATION



ACTS MOBILE SATELLITE COMMUNICATIONS TECHNOLOGY PROGRAM MULTIRATE SPEECH CODEC

The projected configuration for the multirate speech codec under development is shown in the figure. The multirate codec will provide compressed digital speech at 2400, 4800, and 9600 bits per second. At 2400 and 4800 bits per second, the compression technique will be the federal standards for these rates. At 9600 bits per second, the final compression scheme should be the Cellular Telephone Industry Association standard 8000 bits per second coded up to 9600 bits per second. The codec will consist of a base unit and a handset similar to those in use with cellular telephones.

The multirate feature of the codec will allow the data rate to be adaptively varied to compensate for rain fades while maintaining the integrity of the voice link. In particular, in good link conditions, the voice link will operate at 9600 bits per second and provide good quality speech. As the link conditions degrade, the data rate will be switched to 4800 bits per second, to 2400 bits per second, providing a 2-3 dB increase in (clear weather) link margin with each reduction. At 2400 bits per second, the voice link provided will be of communications quality.

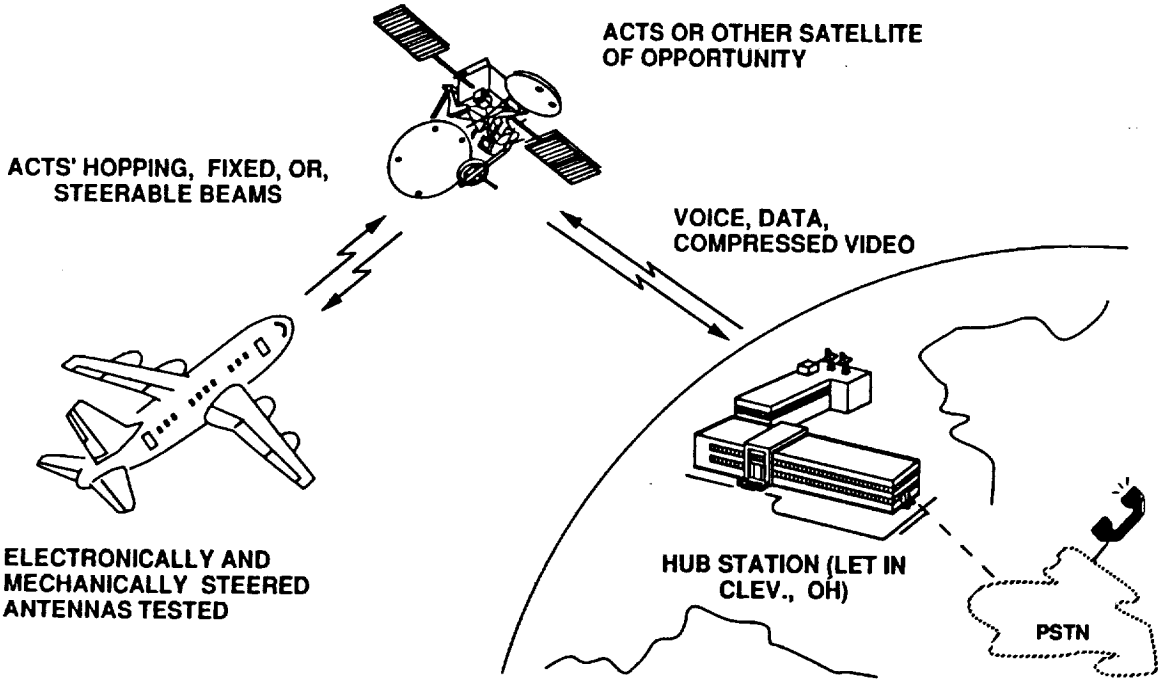
The detailed specification of the codec has been completed. The processor boards that implement the compression algorithms have been selected from an outside vendor. The handset selection, construction of the analog interfaces, and design of the DSP based terminal interface board, are all underway.

TECHNICAL CONTACT: Thomas C. Jedrey, JPL (818) 354-5187 OR FTS 792-5187

JPL

ACTS MOBILE SATCOM TECHNOLOGY PROGRAM

AERONAUTIC COMMUNICATIONS EXPERIMENT



ACTS MOBILE SATELLITE COMMUNICATIONS TECHNOLOGY PROGRAM AERONAUTIC COMMUNICATIONS SYSTEM

The viewgraph depicts the aeronautic communications system experiment setup. Voice, data, FAX, and compressed video will be exchanged between a hub station and an aircraft's cockpit and cabin. Three thrusts for this work are proposed. The first two proposals involve aeronautic communication experiments with ACTS. The last thrust is primarily a study proposal.

The first proposal is the 'low' bit rate experiment wherein the aircraft is outfitted with three electronically steered phased array antennas (under development at LeRC) and a 9.6 Kbps link is maintained between the ground and the aircraft utilizing ACTS. Voice, data, and possible FAX, services will be demonstrated. The experiment will be jointly designed and performed by JPL and LeRC. It is currently in the planning stages and

The second proposal is a 'high' bit rate experiment. It will demonstrate new aeronautic services such as compressed video to the cabin for teleconferencing applications and to the cockpit for FAA and ATC support. This experiment is now in the definition stage. As currently envisioned, it would utilize the core of the AMT equipment: the reflector antenna, the RF and IF converters; terminal controller and data acquisition system. Data rates of $\leq$ 384 kbps can be supported but would require a new modem to be designed. Equipment modification is also necessary to support the higher Doppler offsets encountered and to track the satellite in both azimuth and elevation. An experiment is proposed for FY'94 utilizing ACTS.

The third proposal consists of a study of the communication needs of the aeronautic industry and the design of a aeronautic communication system to meet these needs. An experiment could possibly be undertaken in the FY'97 and beyond timeframe utilizing specialized hardware.

TECHNICAL CONTACT: Polly Estabrook, JPL (818) 354-7403 OR FTS 792-7403

RC MOBILE COMMUNICATION TECHNOLOGY DEVELOPMENT OAET

R&T SCOPE

Develop and test advanced, high risk Mobile Satellite Communications (MSAT) technologies to demonstrate their viability and accelerate transfer of the Mobile Satellite Service (MSS) to U.S. industry. Emphasis placed on critical subsystems of mobile antennas, modems, codes and network protocol.

PAYOFFS

Increased terminal data rates, spectral and power efficiency, and improved robustness in the fading channel. Less expensive, smaller, more efficient and more sensitive antennas. Increased network access throughput, with inherent stability.

BENEFITS

Maintains U.S. preeminence in Satellite Communications Technology. Expands applications of the technology. Supports advocacy of effective spectral utilization, industry development, and public safety.

TECHNICAL CHALLENGE

- Power, spectrum and orbital efficiency
- Robust modulation and coding
- Low cost mobile terminals
- Efficient and stable dynamic channel assignments
- Secure communications

RC MOBILE COMMUNICATION TECHNOLOGY DEVELOPMENT OAET

APPROVED BUDGET	FY91	FY92	FY93	FY94	FY95
JPL (K$)	490	500	500	500	500

MAJOR MILESTONES

FY 1991	19.2 Kbps DBASE experiment and demonstration
FY 1992	Dielectric wedge beam steering - reduces loss 1 dB, and blacklobe 10 dB
FY 1993	Demo 2:1 to 3:1 generalized image source compression, multirate modem
FY 1994	Demo ANSERLIN dual polarized array with 10 dB reduction in blacklobe
FY 1995	Demo multilayer array with 1 dB gain improvement, 20-30% lower cost potential

AGENCY THRUST Primary: Operations

CENTERS JPL **MISSION** Mobile satellite communications

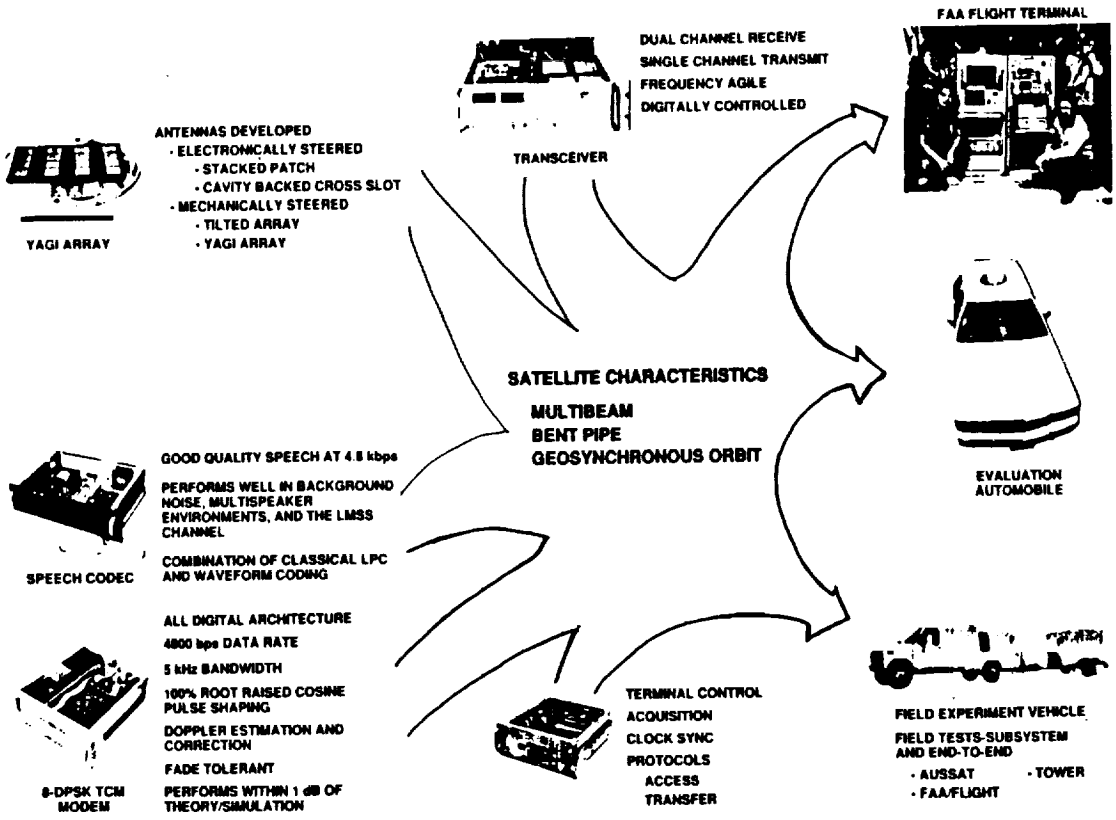
ADEQUACY OF RESOURCES

Resources are appropriate and needed technical staff is on board

CURRENT STATUS Current technology readiness level: 2/5

JPL

MOBILE COMMUNICATION TECHNOLOGY DEVELOPMENT



MOBILE COMMUNICATION TECHNOLOGY DEVELOPMENT

The goals of the Mobile Satellite Program are to develop the technology to accelerate the exploitation of space satellites for a wider base of communications users. The critical and high risk technologies to support Mobile Satellite ground terminals have been identified, developed and tested in the field in end-to-end configurations. During the development emphasis has been placed on the transfer of the technology to industry. The terminal comprises several subsystems: Directive Antenna, Speech Compression, Modem with Forward Error Correction Coding (FEC), Transceiver, and Terminal Controller including access and data transfer protocols. The overall system architecture is based upon a multi-spot beam, bent pipe, Geosynchronous communications payload.

Several approaches to medium gain Directive Antennas have been pursued including both stacked patch and cavity backed slot phased arrays which are electronically steered and tilted and Yagi arrays which are mechanically steered. The Transceiver incorporates dual channel receiver and single channel transmitter sections, each of which is frequency agile and digitally controlled. The pilot channel supports the functions of antenna tracking and doppler frequency correction. The Modem, built with Digital Signal Processors (DSP) implements modulation of the 4.8 KBPS digital data stream, incorporates FEC and interleaving, and demodulation, incorporates bit and frame synchronization, de-interleaving, and Viterbi decoding. The Speech Codec provides good quality voice and adequate speaker recognition at 4.8 KBPS. It is implemented with DSP and includes added FEC to improve robustness in the fading channel. The Terminal Processor integrates the control of the terminal implementing antenna acquisition, re-acquisition, satellite beam recognition, clock synchronization and access and data transfer protocols.

Increasing the performance of the system under the severe constraints imposed by bandwidth, power, orbital slot availability and cost of user terminals challenges the design of antennas, modems and source encoding techniques. Improvements in ground terminal technology permit greater tradeoff flexibility between space and ground segments.

Several configurations of the ground terminal have been integrated into a mobile test van and demonstration vehicle. Field tests and evaluation of the performance of subsystems and the overall system were conducted using satellites of opportunity. Early tests took place along the Southern California Coast with the Pacific Operating Region INMARSAT Beacon. A translator mounted atop the 1000-foot NOAA Wave Propagation Laboratory Tower in Erie, CO provided a surrogate satellite for subsystem and system tests. Complete end-to-end experiments have been conducted with the cooperation of the FAA and INMARSAT for aeronautical applications and Australia's AUSSAT and Japan's Experimental Telecommunications Satellite V (ETS-V).

Satellite Communications Advanced Research (SCAR)

NASA Research Announcement (NRA) Objectives:

- Solicit innovative ideas and technologies that will keep the U.S. preeminent in satellite communications through implementation in the commercial marketplace
- Provide guidance for future NASA program planning
  - Ensure continuing relevance of NASA's communications program to industry needs
  - Identify cutting edge technologies
- Provide U. S. industry with access to NASA-developed techniques/technologies for application in improving satellite commercial service
- NASA support of technology R &D to reduce industry risk and expedite commercial application in improving satellite communications services
- NASA support of technology R & D to reduce industry risk and expedite commercial applications

SATELLITE COMMUNICATIONS ADVANCED RESEARCH (SCAR) PROGRAM

RC OAET

Scope of SCAR Program:

- New processes, methods, or techniques that would enable new communication capabilities or services
  - Examples: research on coding theory, information compression and data organization, distribution, and presentation
- Advancement in the state-of-the-art of technology, materials, or devices
  - Supports improvements in devices or materials such as: Very High Speed Integrated Circuits (VHSIC), Monolithic Microwave Integrated Circuits (MMIC), lasers, composites, mechanisms, etc.
- Advanced communications systems analysis, study of, and research on future communications system concepts that utilize the space element, for the year 2000 and beyond
  - Should be traceable to new space delivered communications capabilities or services

SATELLITE COMMUNICATIONS ADVANCED RESEARCH (SCAR) PROGRAM

RC OAET

APPROVED BUDGET	FY91	FY92	FY93	FY94	FY95
(K$)	2000	2000	2000	2000	2000

MAJOR MILESTONES

FY 1991- 1992	Complete SCAR I contracts
FY 1993	Initiate SCAR II program

CENTERS Hq, LeRC, JPL, GSFC **MISSION** Commercial communications, ACTS

ADEQUACY OF RESOURCES

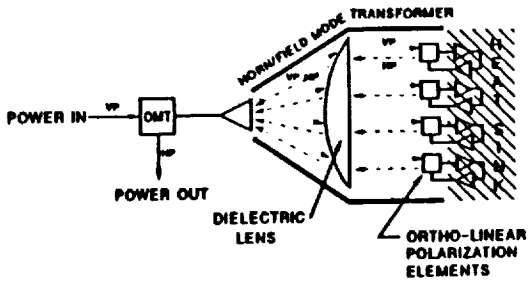
Adequate to fund best industry ideas (industry cost shares)

CURRENT STATUS

Generally midway through SCAR I contracts

SCAR CONTRACT - EFFICIENT, HIGH POWER SOLID STATE AMPLIFIER

ROCKWELL INTERNATIONAL / NASW-4513



OBJECTIVE / SCOPE

- TO DEVELOP AND DEMONSTRATE A NOVEL SPATIAL COMBINING CONCEPT PRODUCING HIGH POWER FROM AN ARRAY OF MMIC AMPLIFIERS
  - PHASE I (9 MO.) - CONDUCT PROOF OF FEASIBILITY INVESTIGATIONS OF POWER COMBINER ONLY (NO MMICs)
  - PHASE II (12 MO) - FABRICATE AND DEMONSTRATE PROOF OF CONCEPT AMPLIFIER WITH MMIC DEVICES

BENEFITS

- NOVEL SPACE COMBINING CONCEPT OFFERS POTENTIAL FOR :
  - IMPROVED HEAT DISSAPATION
  - HIGHER EFFICIENCY AND POWER
  - LOWER COST

  THAN OTHER SOLID STATE AMPLIFIER CONFIGURATIONS

ACCOMPLISHMENTS

- CONTRACT AWARDED OCTOBER 1990
- PHASE I - DESIGN OF ORTHO-LINEAR POLARIZATION ELEMENT, DIELECTRIC LENS COMPLETED
  - TRADE-OFF ANALYSIS OF HORN/FIELD MODE TRANSFORMER CONFIGURATIONS COMPLETED

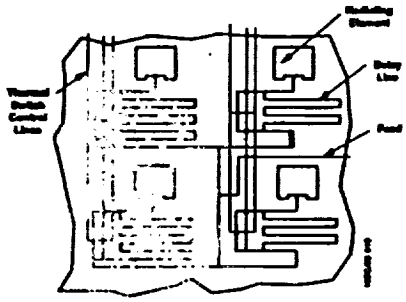
\ SCSCREV \ SCARR

SPACE ELECTRONICS DIVISION

NASA Lewis Research Center

SCAR CONTRACT - SUPERCONDUCTING PHASED ARRAY ANTENNA RESEARCH

BALL AEROSPACE / NASW - 4514W-4513



OBJECTIVE / SCOPE

- TO DEVELOP AND DEMONSTRATE A 4 x 4 SUPERCONDUCTING PHASED ARRAY AT 30 GHz
- TO DEMONSTRATE HTS THERMAL SWITCH FOR PHASE SHIFTER
- TO PERFORM ANTENNA SYSTEM TRADE OFF STUDY

BENEFITS

- REDUCED LOSSES IN BEAM FORMING NETWORK
- REDUCED ANTENNA NOISE

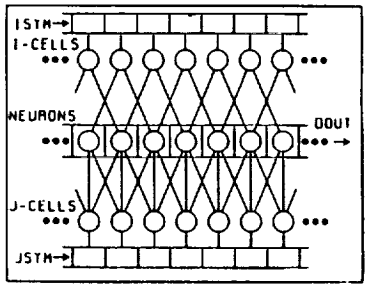
ACCOMPLISHMENTS

- CONTRACT AWARDED JANUARY 1991 FOR PHASE I
- STATEMENT OF WORK REVISED
- 2 x 2 ARRAY DESIGNED AND FABRICATED AT NASA LEWIS

\ SCSCREV \ SCARBALL

SCAR CONTRACT - NEURAL NETWORK-BASED CONVOLUTIONAL DECODER

UNIVERSITY OF CALIFORNIA, SAN DIEGO / NASW-4507



Neural Net Decoder

OBJECTIVE /SCOPE

- TO DEVELOP AND DEMONSTRATE A NEURAL NETWORK CONVOLUTIONAL DECODER FOR SATELLITE COMMUNICATIONS
  - PHASE I (12 MO.) - CONDUCT SOFTWARE SIMULATION TO EVALUATE EFFICIENT NEURAL DECODING ALGORITHMS
  - PHASE II (24 MO.) - DESIGN, FABRICATE, AND TEST THE PROTOTYPES OF THE MOST PROMISING SCHEME IDENTIFY IN PHASE I

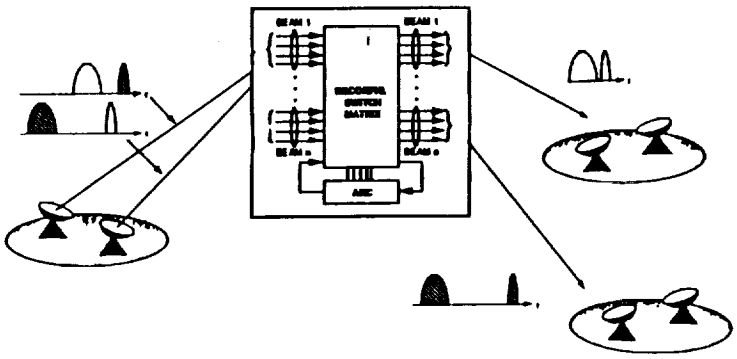
BENEFITS

- EFFICIENT ERROR CORRECTION SCHEME REDUCES BIT ERROR RATE
- SCALABLE DESIGN ALLOWS COMPLEXITY/ SPEED TRADEOFF
- NEURAL NETWORK LEARNS AND ADAPTS TO CHANNEL ERRORS

ACCOMPLISHMENTS

- CONTRACT AWARDED JULY 1990
- DESIGN AND SIMULATION OF A CAM-BASED NEURAL CONVOLUTIONAL DECODER
- DESIGN AND SIMULATION OF A SCALABLE VITERBI DECODER
- PRESENTATION OF A PAPER ON NEURAL DECODER AT IEEE INTERNATIONAL SYMPOSIUM ON CIRCUITS AND SYSTEMS

SCAR CONTRACT COMSAT LABORATORIES / NASW-4528
ON-BOARD B-ISDN FAST PACKET SWITCHING ARCHITECTURES



OBJECTIVES

- CHARACTERIZATION OF B-ISDN SERVICES
- INVESTIGATE FAST PACKET SWITCHING SATELLITE NETWORK ARCHITECTURES
- DEVELOP POC ON-BOARD FAST PACKET SWITCH

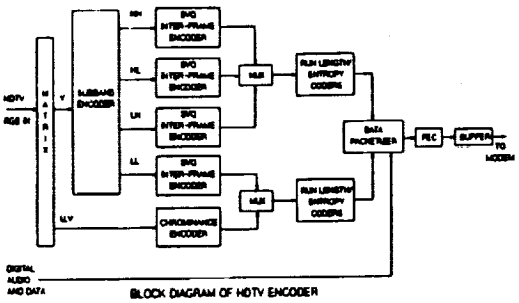
BENEFITS

- COST-EFFECTIVE COMMUNICATIONS
  - HIGH SPEED PRIVATE NETWORKING
  - THIN-ROUTE BROADBAND SERVICES
  - EMERGENCY COMMUNICATIONS
  - HIGH VOLUME DATA DISTRIBUTION
  - TERRESTRIAL NETWORK RESTORATION
  - INTEGRATION OF COMMERCIAL SERVICES AND NASA SPACE MISSIONS

ACCOMPLISHMENTS

- CRITICAL DESIGN ISSUES IDENTIFIED
- VARIOUS NETWORKS ARCHITECTURES INVESTIGATED
- TRADE-OFF ANALYSIS COMPLETE

SCAR CONTRACT - FLEXIBLE RATE HDTV CODEC COMSAT LABORATORIES/NASW-4512



BLOCK DIAGRAM OF HDTV ENCODER

OBJECTIVE/SCOPE

- TO DEVELOP AND DEMONSTRATE A FLEXIBLE-RATE (27-55 Mbps) DIGITAL VIDEO CODEC FOR SATELLITE TRANSMISSION OF HDTV QUALITY VIDEO SIGNALS
  - PHASE I (8 MO.) - EVALUATE CANDIDATE APPROACHES AND SYNTHESIZE FINAL ALGORITHM
  - PHASE II (12 MO.) - BREADBOARD CRITICAL COMPONENTS
  - PHASE III (12 MO.) - CONSTRUCT POC HARDWARE; INTEGRATE & TEST FULL HDTV CODEC

BENEFITS

- ENABLE VIABLE AND COST COMPETITIVE SATELLITE DISTRIBUTION OF HDTV SIGNALS
- EASILY ADAPTABLE TO BROAD RANGE OF TERRESTRIAL HDTV TRANSMISSION FORMATS
- HIGH PROBABILITY FOR COMMERCIALIZATION OF DEVELOPED TECHNOLOGY

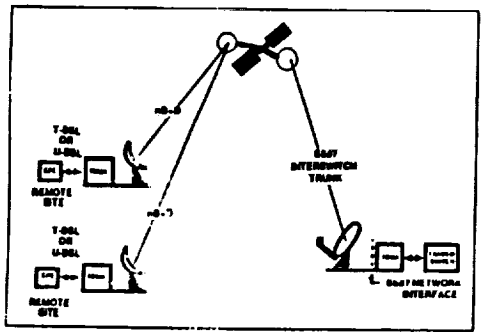
ACCOMPLISHMENTS

- CONTRACT AWARDED OCTOBER 1990
- PHASE I COMPLETED
  - MOTION COMPENSATED SUBBAND CODING APPROACH SELECTED
  - SIMPLIFIED VECTOR QUANTIZATION (SVQ) FOR CODING OF INDIVIDUAL SUBBANDS

SCAR CONTRACT - ADVANCED SATELLITE DESIGNS AND EXPERIMENTS FOR ISDN SERVICES

CONTEL TECHNOLOGY CENTER AND UNIVERSITY OF COLORADO / NASW-4520

SATELLITE ISDN SERVICES



OBJECTIVE / SCOPE

- TO DEMONSTRATE SATELLITE ISDN SERVICES VIA ISDN APPLICATION TESTBED
  - PHASE I (12 MONTHS) - DEVELOP NETWORK AND TRAFFIC MODEL, SCENARIO AND PERFORMANCE SPECIFICATIONS
  - PHASE II (12 MONTHS) - COMPLETE HARDWARE IMPLEMENTATION FOR FULL SERVICE ISDN SATELLITE
  - PHASE III (12 MONTHS) - PERFORM HARDWARE AND SOFTWARE SIMULATOR EXPERIMENTATION

BENEFITS

- RURAL AND REMOTE ACCESS ISDN SERVICES
- NATIONWIDE ISDN CONNECTIVITY
- REDUCED ISDN TERMINAL COST

ACCOMPLISHMENTS

- CONTRACT AWARDED SEPTEMBER 1990
- ISDN LITERATURE SEARCH COMPLETED
- PRELIMINARY ISDN TERMINAL HARDWARE DESIGN COMPLETED
- PRELIMINARY NETWORK AND TRAFFIC MODEL COMPLETED

TECHNICAL WORKING GROUP MEETING
ON
R & T SPECIAL TOPICS

PHOTONICS
TECHNOLOGY PROJECT SUMMARY

JUNE 27, 1991

Dr. Ramon P. De Paula

OFFICE OF AERONAUTICS AND EXPLORATION TECHNOLOGY
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, DC

CO2

WHAT IS PHOTONICS?

PHOTONICS INVOLVES THE USE OF LIGHT (PHOTONS) IN CONJUNCTION WITH ELECTRONICS FOR APPLICATIONS IN COMMUNICATIONS, COMPUTING, CONTROL AND SENSING.

COMPONENTS USED IN PHOTONIC SYSTEMS INCLUDE LASERS, OPTICAL DETECTORS, OPTICAL WAVE GUIDE DEVICES, AND FIBER OPTICS, AS WELL AS TRADITIONAL ELECTRONIC DEVICES.

RC

PHOTONICS

OAET

GOALS AND OBJECTIVES

- DEVELOP HYBRID OPTOELECTRONIC DEVICES AND SYSTEMS FOR SENSING, INFORMATION PROCESSING, COMMUNICATIONS, AND CONTROL THAT WILL ENABLE AT LEAST AN ORDER OF MAGNITUDE IMPROVEMENT IN PERFORMANCE OVER EXISTING TECHNOLOGY IN MEETING NASA MISSION REQUIREMENTS.
- CONDUCT R&D IN THE FOLLOWING AREAS:
  - MATERIALS AND DEVICES
  - NETWORKING AND COMPUTING
  - OPTICAL PROCESSING/ADVANCED PATTERN RECOGNITION
  - SENSING

RC

PHOTONICS

OAET

BENEFITS

- INFORMATION SYSTEMS AND NETWORKING AT Gbit/sec RATES, WITH Tbyte STORAGE CAPACITY AND COMPONENTS FOR DECODING AND MULTIPLEXING WITH 10 TO 1000X LESS POWER CONSUMPTION
- MIXING AND MODULATING OF mm AND SUB-mm WAVE SIGNALS IN THE OPTICAL DOMAIN TO BYPASS MICROCIRCUIT CONSTRAINTS
- SPECIAL-PURPOSE PROCESSING FOR OBJECT RECOGNITION AND HAZARD DETECTION AT 10^4 TO 10^5 MIPS/WATT (100x CURRENT CAPABILITY) WHILE OFF-LOADING SYSTEM GENERAL PURPOSE COMPUTING CAPACITY.
- LASER SENSING AT NEW WAVELENGTHS (eg. 2-5 μm, LONG IR) WITH COMPACT DIODE LASERS. NEW TUNABLE LASERS.
- OPTICAL FEED AND CONTROL OF 10^4TO 10^5 ELEMENT ANTENNA ARRAYS FOR BEAM STEERING WITHOUT ANTENNA SLEWING.
- FIBER OPTIC INTERFEROMETRY TO SIMPLIFY CONTROL AND MECHANICAL DESIGN; DECREASE ATMOSPHERIC FLUCTUATIONS IN PATH LENGTH FOR EARHT-BASED SYSTEM

RC

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APPROACH

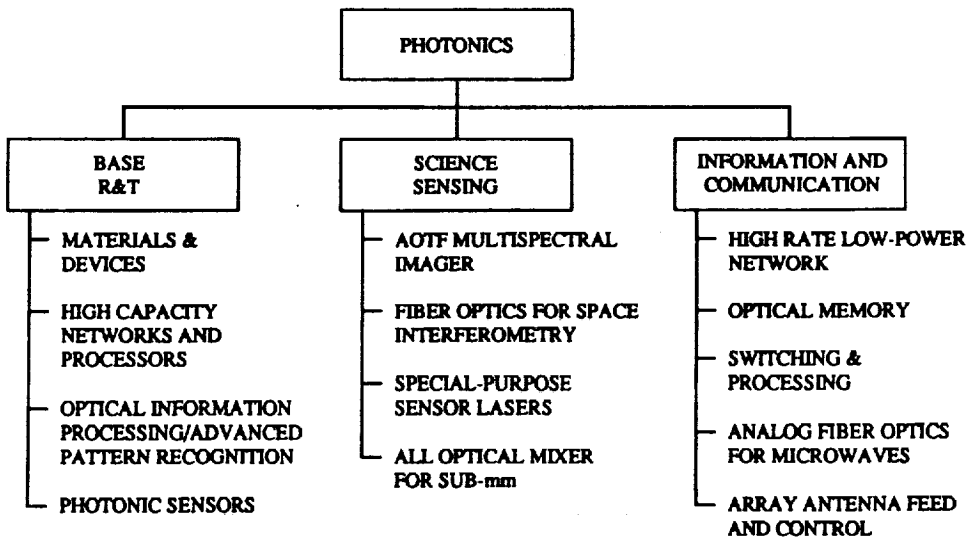
- **BASE PROGRAM**
  - INVESTIGATES NEW SYSTEM CONCEPTS AND DEVELOPS NEEDED DEVICES
  - LAYS FOUNDATION FOR FOCUSED PROGRAM EFFORTS
  - SELECTS TECHNOLOGY AREAS LIKELY TO HAVE A SIGNIFICANT EFFECT ON THE WAY FUTURE PROJECTS ARE CARRIED OUT
  - DEDICATES A FRACTION (~10% OF PROGRAM RESOURCES) TO SMALL TASKS DIRECTED TOWARD IDENTIFYING OR DEVELOPING PROMISING CONCEPTS FOR FUTURE DEVELOPMENT (INNOVATIVE CONCEPTS)
  - ESTABLISHES A STRONG UNIVERSITY INVOLVEMENT IN THIS AREA
- **FOCUSED PROGRAMS**
  - SCIENCE SENSING
  - INFORMATION
    - PURSUE TASKS THAT CAN LEAD TO LEVEL 5 BREADBOARD DEMOS IN 5 YEARS, MAINTAIN COUPLING WITH USERS THROUGHOUT THE COURSE OF THE WORK

RC

PHOTONICS

OAET

PROGRAM ORGANIZATION

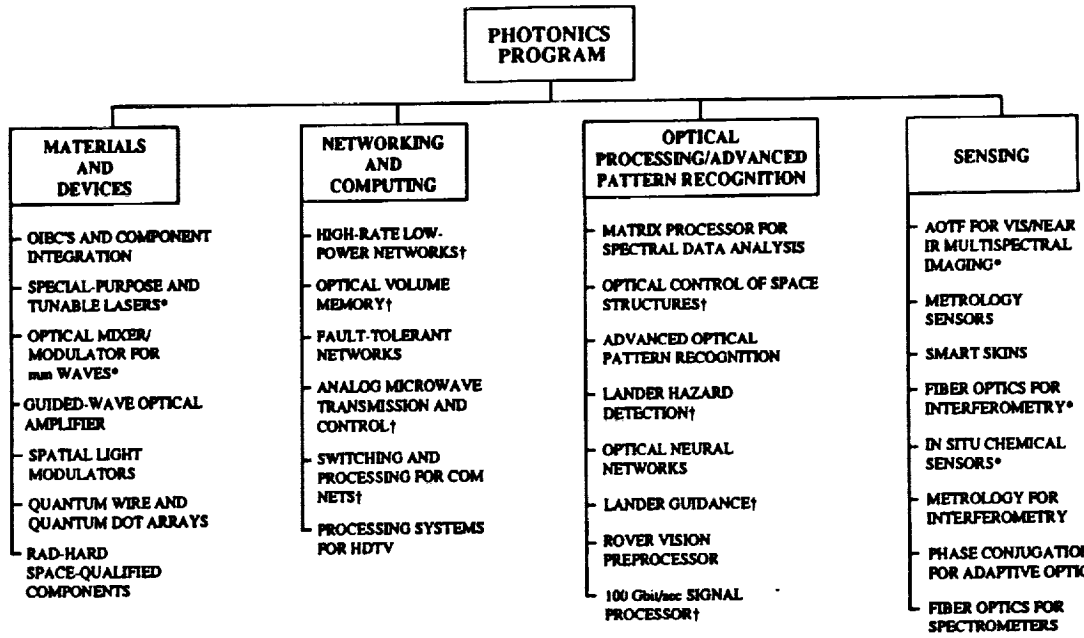


RC

PHOTONICS

OAET

WORK BREAKDOWN STRUCTURE



* SCIENCE
† OPERATIONS
} FOCUSED PROGRAM ELEMENTS
BREADBOARD DEMO IN ≤ 5 YEARS

RC

PHOTONICS

OAET

TECHNOLOGY AREA	CURRENT STATE OF THE ART	TECHNOLOGY GOALS
MATERIALS AND DEVICES		
• OPTICAL WAVEGUIDE DEVICES	• WAVEGUIDE DEVICES IN $LiNbO_3$ LOSS 0.1 dB/cm MODULATION FREQUENCY 10GHz INTEGRATION LEVEL 9 TO 10 DEVICES	• FULL INTEGRATION IN III-V SEMICONDUCTORS LOSS 0.1 dB/cm FREQUENCY 10-100 Ghz INTEGRATION ~100 DEVICES -i.e. SUFFICIENT TO IMPLEMENT NETWORK INTERFACE, ADDRESS DECODER
• SPECIAL PURPOSE LASERS FOR SENSING	• LASERS EMPHASIZE 0.8, 1.3, 1.5m EFFICIENCY – 5%	• SPECIAL WAVELENGTHS; e.g. 2.1 μm FOR LAWS; 3-10 μM FOR SPECTROSCOPY POWER 100 MW EFFICIENCY 50%
• OPTICAL MIXER FOR THE SUB-mm	• DIODE DETECTOR ARRAYS, FREQUENCY 500-800 Ghz	• NONLINEAR OPTICAL MATERIAL FREQUENCY 3 Thz NOISE 10X THE QUANTUM LIMIT IMAGE SIZE 100X100
NETWORKING AND COMPUTING		
• HIGH RATE, LOW POWER NETWORKS	• ETHERNET: FEW Mbit; FDDI 100 MBIT FIBER RING HPPI 800 MBIT SONET 2.4 GBIT FOR TELCOM LATENCY 1 ms POWER/NODE 30-50 W (FDDI)	• TRIPLE FAULT TOLERANT OPTICAL FIBER, PROBABLY EVOLUTIONARY FROM FDDI, HPPI DATA RATE 3 GBIT/SEC LATENCY 1-10 mSEC POWER/NODE 1 WATT
• MASS MEMORY	• MAG DISC SYSTEMS: CAPACITY GBYTES I/O RATE 30 Mbit/sec ACCESS TIME 15 ms	• OPTICAL VOLUME MEDIUM CAPACITY Tbytes I/O RATE 1 Gbit/sec ACCESS TIME < 1 μsec
• ANALOG MICROWAVE TRANSMISSION	• WAVEGUIDE PLUMBING; STRIPLINE FREQUENCY X BAND 10 GHz LIMITED TRANSMISSION DISTANCE	• OPTICAL FIBER WITH MICROWAVE XMIT/RECEIVE MODULES FREQUENCY X BAND 10 GHz, Ka BAND 32 GHz LOSS 2-3 dB/km DYNAMIC RANGE 120 dB

RC

PHOTONICS

OAET

TECHNOLOGY AREA	CURRENT STATE OF THE ART	TECHNOLOGY GOALS
OPTICAL PROCESSING • MATRIX PROCESSOR FOR SPECTRAL ANALYSIS	• ELECTRONIC DIGITAL PROCESSING OFFLINE PROCESSING OF SSME PLUME DATA FOR ANOMALY DETECTION NO ENGINE SHUTDOWN CAPABILITY 16 LINE SPECTRAL ANALYSIS AT 1 Khz	• AO ARRAY OPTICAL MATRIX PROCESSOR 2000 LINE SPECTRAL DATA ANALYSIS AT 1 kHz ENGINE SHUTDOWN CAPABILITY
• STRUCTURE CONTROL PROCESSOR	• DIGITAL ELECTRONIC FEEDBACK CONTROL ~10^2 SENSORS AND ACTUATORS VIBRATION DAMPING AT 35 Hz	• OPTICAL FEEDBACK LOOP >10 SENSORS AND ACTUATORS VIBRATION DAMPING AT 1 KHz
• ADVANCED OPTICAL PATTERN RECOGNITION	• DIGITAL ELECTRONIC PROCESSING 60 Hz COOPERATIVE TARGET NON REAL-TIME WITH UNMARKED OBJECT	• OPTICAL CORRELATION 100 Gops EQUIVALENT NON COOPERATIVE TARGET AT 60 Hz 200 cc, 1 kg, <30 W
• LANDER HAZARD DETECTION	• RADAR TECHNOLOGY; NO HAZARD DETECTION ALGORITHMS HAVE BEEN IMPLEMENTED, ~10 m FOOTPRINT	• OPTICAL NEURAL PROCESSOR DETECT ≥ 1/2 m ROCK OR SCRAP 30 IMAGES/sec, <50 W, 1 cu ft, 10 lb
SENSING • AOTF MULTISPECTRAL IMAGER	• MULTISPECTRAL IMAGING EITHER BY FILTER WHEEL OR LARGE INSTRUMENT LIKE HIRIS OPERATING IN PUSHBROOM MODE	• TeO2 AOTF VIS AND NEAR IR IR TAS AOTF FOR MID-IR 30 FRAMES/sec, 1-10 nm SPECTRAL WIDTH 200X200 PIXEL FRAME WAVELENGTH RANGE 1-2 OCTAVES FOR ONE AOTF CRYSTAL
• FIBER OPTICS FOR INTERFEROMETRY	• FREE SPACE OPTICS IN INTERFEROMETER 3 DIMENSIONAL ADJUSTMENT	• INTERFEROMETER PATHS IN FIBER OPTIC WAVEGUIDE ONE DIMENSIONAL CONTROL
• METROLOGY SENSORS	• SURVEYING AND MACHINE SHOP INSTRUMENTS	• PHASE LOCKED LASER ACCURACY ~10 SCANNABLE SETTLING TIME ~1 ms

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TECHNOLOGY CHALLENGES

TECHNOLOGY AREA	TECHNOLOGY CHALLENGE
OPTOELECTRONIC INTEGRATED CIRCUITS (OEIC'S)	• INTEGRATION OF OPTOELECTRONIC & ELECTRONIC COMPONENTS • YIELD • NUMBER OF COMPONENTS/CHIP SUFFICIENT TO ENABLE USEFUL SYSTEM FUNCTIONS TO BE ACHIEVED
AOTF MULTISPECTRAL IMAGING	• LARGE, HIGH QUALITY ACOUSTO-OPTIC CRYSTALS, ESPECIALLY FOR THE IR • RESOLUTION, PHOTOMETRIC EFFICIENCY AND ACCURACY
HIGH RATE OPTICAL NETWORKING	• LOW POWER PER NODE • ULTRA HIGH RELIABILITY; LONG LIFE, WITH DESIGN FOR GRACEFUL DEGRADATION FOR ANY FAILURE
MASS MEMORY	• USE OF VOLUME MEDIA FOR STORAGE TO ACHIEVE LARGE INCREASE IN INFORMATION DENSITY • HIGH RELIABILITY AND LONG LIFE
OPTICAL SUB mm MIXERS	• NONLINEAR MATERIALS • DEVICE ARRAY CONCEPTS • LOW CONVERSION NOISE
HAZARD DETECTION FOR PLANETARY LANDING; ROVER VISION	• ADVANCED SLM's • ROBUST ALGORITHMS
OPTICAL PROCESSING/ADVANCED PATTERN RECOGNITION	• ADVANCED SOLID-STATE SLM's • SPECIAL PURPOSE ALGORITHMS FOR COMPUTING/PREPROCESSING • ROTATION AND SCALE INVARIANT ALGORITHMS FOR PATTERN RECOGNITION

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TECHNOLOGY CHALLENGES (CON'T)

TECHNOLOGY AREA	TECHNOLOGY CHALLENGE
SPATIAL LIGHT MODULATORS	• ROBUST, ALL SOLID STATE DEVICES CAPABLE OF TV RESOLUTION AND SPEED
SPECIAL-PURPOSE LASERS	• APPLICATION OF MBE, MOCVD TECHNOLOGY TO NEW DEVICE STRUCTURES TO OBTAIN NEW WAVELENGTHS • STABLE OPERATION AND LONG DEVICE LIFE; SPACE QUALIFICATION • TUNABILITY • HIGH POWER PHASED ARRAYS FOR OPTICAL COM
SWITCHING AND IN-LINE PROCESSING FOR COMMUNICATION	• LOW-POWER, VERY HIGH THROUGHPUT IN-LINE REAL-TIME FILTERS, PROCESSORS AND SWITCHES
OPTOELECTRONIC MICROWAVE ANTENNA ARRAY FEED AND CONTROL	• SYSTEM ARCHITECTURE • SIMPLE PROCESSORS FOR DELAY GENERATION • COMPOSITE STRUCTURES
OPTICAL FIBER ANALOG MICROWAVE SIGNAL TRANSMISSION	• DYNAMIC RANGE; HARMONICS • HIGH-FREQUENCY MODULATORS
SPACE ENVIRONMENTAL EFFECTS ON OPTOELECTRONICS	• MODELS TO PREDICT LONG-TERM PERFORMANCE • APPROACHES TO REDUCE EFFECTS OF RADIATION AND POLYMER AGING

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FUTURE NASA NEEDS

1. SPECIALIZED INTEGRATED WAVEGUIDE DEVICES FOR MODULATING, AMPLIFYING, DETECTING, AND EMITTING REQUIRED FOR COMMUNICATIONS AND INFORMATION SYSTEMS; BY 2003
   - MISSIONS: ALL MISSIONS, AND GROUND SYSTEMS

2. HIGH RATE, LOW POWER, ULTRA RELIABLE DIGITAL PROCESSING, NETWORKING, STORAGE, AND DISPLAY BY 2002
   - MISSIONS: OVBLI-NG; LDR; OVBLI; HIRIS; PF; NOP; (ALL)

3. OPTOELECTRONIC SYSTEMS FOR TRANSMISSION AND CONTROL OF MICROWAVE SIGNALS IN COMMUNICATION SYSTEMS AND ARRAY ANTENNAS BY 2001
   - MISSIONS: ALL MISSIONS, AND GROUND SYSTEMS

4. LOW POWER, REAL-TIME OPTICAL PREPROCESSORS FOR PLANETARY LANDING, ROVERS, AND SURFACE SCIENCE BY 2003
   - MISSIONS: LUNAR, PLANETARY LANDERS; ROVERS; CNSR; SMMI

5. COMPACT, SIMPLE AND AGILE IMAGING SPECTROMETER FOR VIS, IR BY 1999
   - MISSIONS: LTT; OSI; ST-NG; SMMM LDR SMMI; MR

6. OPTICAL FIBERS, LASER METROLOGY AND TECHNOLOGY FOR SPACE INTERFEROMETRY BY 1999
   - MISSIONS: MOI; SMMI

7. RAD-HARD, RELIABLE TECHNOLOGY FOR OPTOELECTRONIC DEVICES AND SYSTEMS BY 1999
   - MISSIONS: ALL MISSIONS

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PRESENT PROGRAM

- DEVELOPMENT OF OPTOELECTRONIC INTEGRATED CIRCUITS AT THE JPL MDL
- SPECIALIZED OPTICAL COMPUTING AND PATTERN RECOGNITION AT ARC
- SPACE ENVIRONMENTAL EFFECTS ON FIBER OPTICS AT JPL

THE PRESENT PROGRAM IS BELOW CRITICAL MASS WITH EXTREMELY LIMITED FUNDS, AND DOES NOT ALLOW EXPLORATION OF MANY OPPORTUNITIES FOR NEW DEVICES AND SYSTEMS THAT ARE COMING OUT OF THE BROAD PHOTONICS TECHNOLOGY AREA

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CURRENT PROGRAM MILESTONES

OPTOELECTRONIC INTEGRATED CIRCUITS

FY 1991	DEMONSTRATE GROWTH OF InP MATERIAL, CONSTRUCT CHARACTERIZATION AND ANALYSIS SYSTEMS
FY 1992	DEMONSTRATE PASSIVE WAVEGUIDE COMPONENTS: WAVEGUIDES w/<1 dB/cm LOSS, y-BRANCHES w/<1 dB EXCESS INSERTION LOSS
FY 1994	INTEGRATE DEVICES INTO TARGET OEICs

ADVANCED OPTICAL PATTERN RECOGNITION

FY 1993	REAL-TIME GRAPPLING OF ARBITRARILY ORIENTED, MOVING OBJECTS
FY 1994	DEVELOPMENT OF FLIGHT DEMONSTRATION OF AUTONOMOUS VISION
FY 1995	COMPACT OPTICAL CORRELATOR

OPTICAL CONTROL OF SPACE STRUCTURES

FY 1992	OPTICAL CONTROL OF A SEGMENTED MIRROR
FY 1993	ALGORITHMS FOR CONTROL OF A SPACE STRUCTURE FOR VIBRATION DAMPING
FY 1995	CONTROL OF SPACE STRUCTURE MODELS AT 1000 Hz

SPACE ENVIRONMENTAL EFFECTS ON FIBER OPTICS

FY 1991	DATA ANALYSIS OF LDEF COMPLETE
FY 1993	EVALUATE AND TEST IMPROVED FIBER CABLE

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ACCOMPLISHMENTS

- DEMONSTRATED IDENTIFICATION, TRACKING AND GRASPING OF UNMARKED AND ROTATED OBJECTS WITH OPTICAL CORRELATION BASED VISION SYSTEM
- OPTICAL PATTERN RECOGNITION SYSTEM USED OVER A REMOTE VIDEO LINK TO CONTROL AN INDUSTRIAL ROBOT
- REPORTED RESULTS TO DATE FROM LDEF FIBER OPTIC EXPERIMENT AT LDEF EXPERIMENTERS SYMPOSIUM
- BUILT ADAPTIVE TELESCOPE CONTROL TESTBED AND DESIGNED OPTICAL MATRIX PROCESSOR BASED CONTROL SYSTEM
- CHARACTERIZATION TECHNIQUES FOR OEIC DEVICES DEVELOPED
- NEW MOCVD REACTOR FOR OEIC FABRICATION ORDERED

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RELATED NASA EFFORTS

- OPTICAL COMMUNICATIONS PROGRAM (JPL, GSFC)
- LASER SENSING AND SUB mm RECEIVER ELEMENTS OF SCIENCE SENSING PROGRAM (LaRC, JPL)
- SENSOR (ie. CCD) READOUTS ELEMENT OF SCIENCE SENSING PROGRAM (JPL)
- A&E PROGRAM ELEMENTS RELATED TO VISION (JPL)
- FORS DEVELOPMENT (JPL)
- OPTICAL FIBER AND RELATED WORK IN JPL Div. 33 FOR TDA
- TAOS (JPL)
- DATA SYSTEM PLANNING FOR FUTURE GRAPHICS & DISPLAY HANDLING (GROUND SYSTEMS, JPL Div. 36)
- NON-DESTRUCTIVE TESTING; METROLOGY, IN SITU SENSORS, AND FIBER OPTIC SMART SKINS (LaRC)
- FOCI (LeRC)
- OPTICAL PROCESSING AND PATTERN RECOGNITION (JSC)

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OTHER NON-NASA PHOTONICS EFFORTS

- JPL MDL; SUPPORT BY SDI, DOD SPONSORS AS WELL AS NASA. WIDE RANGE OF MICRODEVICE DEVELOPMENT CAPABILITY, BOTH OPTOELECTRONIC AND ELECTRONIC DEVICES
- DARPA - OPTOELECTRONICS PROGRAM (A. YANG AND IRA RICHER)
- RADC - OPTOELECTRONICS PROGRAM (BRIAN HENDRICKSON)
- UNIVERSITY PROGRAMS
  - INCLUDES CALTECH, UCSB, UCSD, U. OF COLO, GEORGIA TECH, etc.
  - NATIONAL CENTER FOR INTEGRATED PHOTONIC TECHNOLOGY (USC)
  - UNIVERSITY PHOTONICS CONSORTIUM
- BELL LABS, BELLCORE, HONEYWELL, 3M, XEROX, etc.
- EUROPEAN & JAPANESE PROGRAMS

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PHOTONICS

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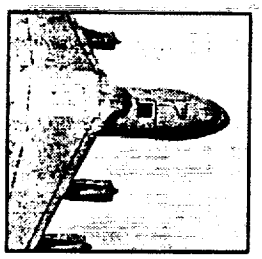
EXISTING PROGRAM RESOURCES

FUNDING IN M$

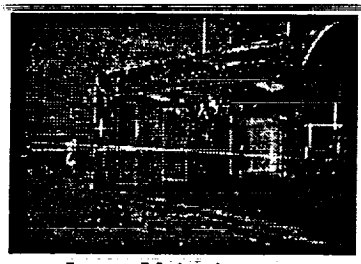
	91	92	93	94	95	96	97
BASE PROGRAM	0.6	0.6	0.6	0.7	0.8	0.9	1.0

NASA PHOTONICS FACILITIES

Ames Photonics Facilities



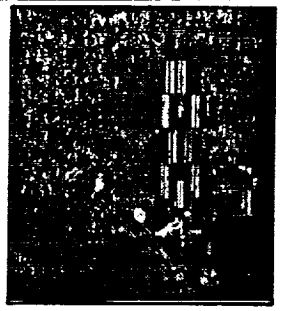
Kuiper Airborne Observatory



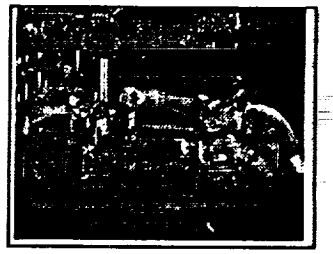
Laser Velocimetry Laboratory

Photonic Processing Laboratory

Optical Pattern Recognition Testbed



Optical Control Testbed



Optical Neural Network Testbed

NASA
Ames Research Center

Ames Photonics Facilities

Kuiper Airborne Observatory
A modified C141 transport aircraft which serves as a high-altitude infrared atronomical observing platform. Kuiper significantly enhances suborbital observing capabilities and complements NASA's Great Observatories.

Laser Velocimetry Laboratory
Three component, laser doppler velocimeter for the 7- by 1-Foot Wind Tunnel and a large-scale, two-component, laser doppler velocimeter for the 40- by 80-Foot Wind Tunnel.

Photonic Processing Laboratory
A state-of-the-art facility specifically designed for optical processing research located in the new Automation Sciences Research Facility (ASRF). The laboratory contains four separate research bays, each with a 4'x12' air-bearing optically isolated table and associated lab benches. Each bay has separate lighting controls, cooling water for high-power lasers, compressed air, and electrical connections.

The lab also has two Sparc I, one Sparc II, and three 3/60 Sun workstations on a local network fileserver, a Masscomp 5600 computer, and 386 and 286 lab PCs. The Sun system includes two Androx image processing boards containing high-speed digital signal processing (DSP) chips. A large suite of image processing software is also available for simulation.

Optical Pattern Recognition Testbed
Located in the Photonic Processing Laboratory, the testbed contains a high-speed optical correlator, four Semetex Magneto-Optic Spatial Light Modulators, two of which are the latest versions with update rates of several 100 Hz, and a large array of optical components and positioning equipment. The testbed also includes a Microbot robot for autonomous vision research.

Optical Control Testbed
The Optical Control Testbed, located in the Photonic Processing Laboratory, contains a breadboard optical matrix processor. For research in control of space structures, the lab has a custom-built 13 segment mirror with 39 separate piezo-electric drivers and their associated amplifiers.

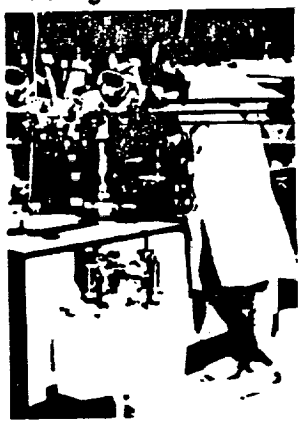
Optical Neural Network Testbed
This testbed, also located in the Photonic Processing Laboratory, contains a variety of optical equipment for testing optical neural networks which use free-space optical interconnections implemented holographically. Available equipment includes a Newport Thermoplastic Holographic Recorder and a Hamamatsu Micro-Channel Spatial Light Modulator capable of controlled optical thresholding operations.

NASA
Ames Research Center

JPL Photonics Related Facilities at JPL

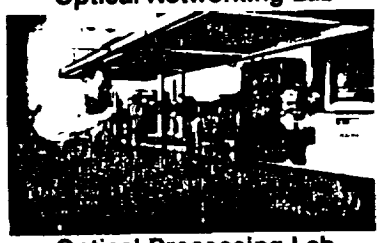
Center for Space Microelectronics Technology Microdevices Laboratory

- 38,000 sq ft of laboratory and office space
- 65 people
- Current device projects include special lasers, IR detectors, sub mm devices and optical waveguide devices



- Facilities include MBE, MOCVD, LPE and full range of support equipment for device fab, lithography and characterization

Optical Networking Lab



Optical Processing Lab

In P Growth Facility for OIECS

PHOTONICS RELATED FACILITIES AT JPL

1. MDL

The Microdevices Laboratory (MDL) is a state-of-the-art facility dedicated to long-range research and advanced development of electronic materials and solid-state devices that support the space mission requirements of the National Aeronautics and Space Administration (NASA) and the U.S. Department of Defense (DOD).

MDL is a primary research facility for the Jet Propulsion Labortory (JPL) Center for Space Microelectronics Technology (CSMT) and is operated by JPL's Space Microelectronic Device Technology Section (346). MDL enables the development of a multiple of advanced space microelectronic devices such as infrated detectors, millimeter and submillimeter wave sensors, optoelectronic devices, and electronic neural networks. Solid-state devices down to submicron feature size are fabricated in MDL using semiconductors, and superconductors. These devices are characterized for their electrical, optical, amd surface/interface properties.

With its state-of-the-art equipment and creative atmosphere, MDL adds a new dimension to JPL's effort in advanced microelectronic devices for space applications.

2. FIBER NETWORKING LAB

xxx sq ft of laboratory area, including both optical bench areas and adjoining electronics labs. The photograph illustrates a picosecond erbium fiber ring laser to be used for an optical network protocols experiment.

3. OPTICAL PROCESSING LABORATORY

This lab includes xxx sq ft of work space and four separate optical table areas. Two high power lasers are available for optical processing experiments, as wel as a range of supporting equipment.

4. InP GROWTH FACILITY

This laboratory, located in the MDL, is being built up for the purpose of fabricating waveguides and waveguide devices, ultimately in integrated form as OEIC's. The photograph illustrates xxx

05/23/91

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NEW AUGMENTATION

REQUESTED TO PHOTONICS

PROGRAM

INTEGRATED TECHNOLOGY PLAN

R & T BASE TECHNOLOGY PROGRAM

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JUSTIFICATION

- Fundamental research is needed to develop hybrid photonic devices and systems for sensing, information processing, communications and control that will demonstrate an order of magnitude improvement in performance relative to existing technology

OBJECTIVES

- **Programmatic**
  Develop innovative concepts and demonstrate the feasibility of optoelectronic components to satisfy future requirements and associated with science and data handling applications
- **Technical Areas**
  - Materials and devices to support specialized requirements
  - High capacity networks and processors
  - Optical information processing and advanced optical pattern recognition
  - Photonic sensors for science and space structures

PHOTONICS FOR R&T BASE

MILESTONES

- 1994 – Demonstrate an integrated OEIC for com applications
- 1995 – Demonstrate components for AOTF spectrometer
- 1996 – Demonstrate a structure control processor
- 1996 – Demonstrate feasibility of an OEIC device for a 3 Gbit/sec network
- 1996 – Demonstrate a scannable 10E-7 optical metrology sensor
- 1997 – Demonstrate an optical processor integrated into an EOS data system
- 1998 – Demonstrate smart skin sensors for space structures
- 1998 – Demonstrate a fault-tolerant network for space systems
- 1999 – Demonstrate a landing hazard detector breadboard

RESOURCES

Budget ($,M)	1993	1994	1995	1996	1997
CURRENT	0.6	0.7	0.8	0.9	1.0
'93 REQUEST	3	3	4	4	5

- **Basis for Estimate**
  Augmentation needed to provide a technology base to satisfy mission requirements for sensor systems

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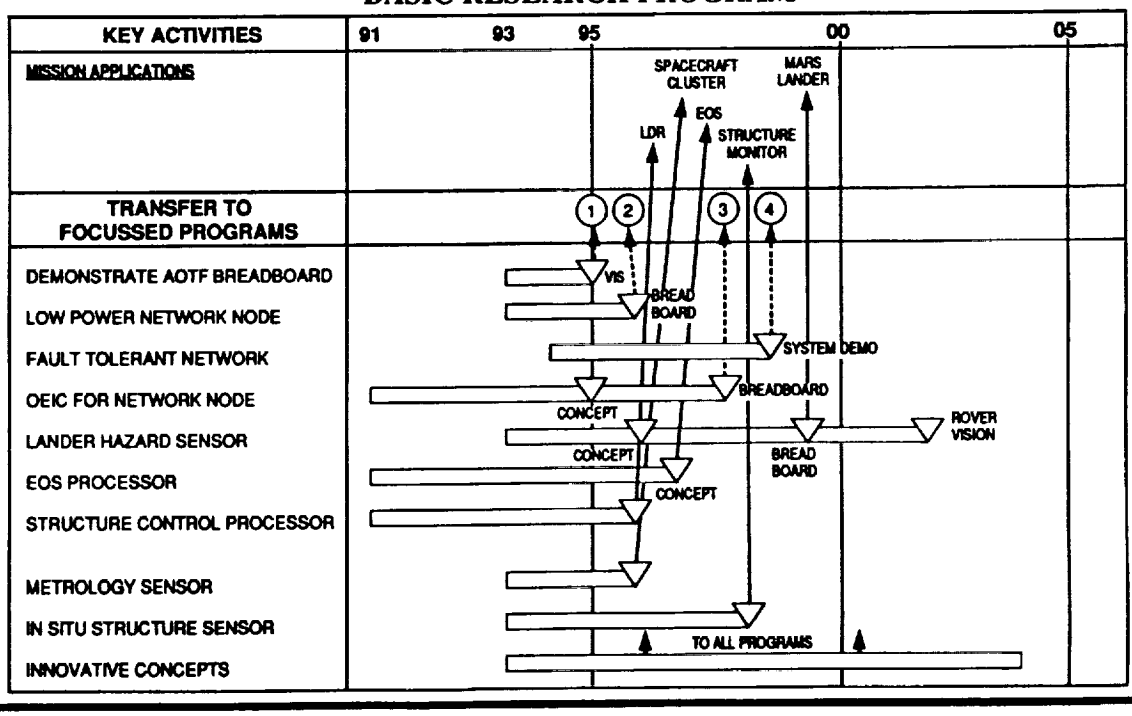
TECHNOLOGY ROADMAP/SCHEDULE

BASIC RESEARCH PROGRAM



INTEGRATED TECHNOLOGY PLAN

SCIENCE TECHNOLOGY PROGRAM

OAET

SENSOR TECHNOLOGY

JUSTFICATION

- **Mission Needs**
  - AOTF multispectral imager for mid- and far-infrared with improved resolution, accuracy and phtometric efficiency
  - Improved signal processing reliability, speed and capacity
  - Array technology to improve sensor performance
- **Missions**
  - OSI
  - ST-NG
  - SMMM
  - MOI
  - SMMI
  - EOS-B

OBJECTIVES

- **Programmatic**
  Demonstrate the feasibility of optoelectronic components for specific science and data handling applications. Provide at least an order of magnitude improvement in performance at technology readiness level 5
- **Technical Areas**
  - Long-life, stable, tunable diode lasers operating at new wavelengths
  - Low noise mm-wave optical mixers for array operations
  - AOTF multispectral imager
  - Fiber optic interferometer

PHOTONICS SCIENCE SENSING

MILESTONES

- 1996 – Demonstrate feasibility breadboard of optical submm mixer
- 1997 – Demonstrate AOTF for 2.5μm to 5μm
- 1997 – Demonstrate diode laser for spectrometry
- 1998 – Demonstrate 1.2THz optical modulator mixer
- 1998 – Demonstrate baseline fiber-optic space interferometer
- 2000 – Demonstrate superlattice submm detector array
- 2001 – Demonstrate an 8μm to 12μm AOTF spectral imager
- 2003 – Demonstrate an advanced fiber-optic interferometer

RESOURCES

Budget ($,M)	1993	1994	1995	1996	1997
CURRENT	—	—	—	—	—
'93 REQUEST	—	—	4	4.5	5

- **Basis for Estimate**
  Augmentation needed to provide a technology base to satisfy mission requirements for sensor systems

INTEGRATED TECHNOLOGY PLAN

OPERATIONS TECHNOLOGY PROGRAM

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INFORMATION & COMMUNICATIONS TECHNOLOGY

JUSTFICATION

- **Mission Needs**
  - Multimegabit/sec information systems
  - Low-cost microwave arrays
  - 100 Gbit/sec cross correlator
- **Missions**
  - OVBI-IVS,
  - LDR,
  - Rovers
  - Communications satellites
  - HIRIS
  - MODIS
  - SMMI

OBJECTIVES

- **Programmatic**
  Develop specific optoelectronic subsystems and systems for information processing and communications that will enable at least an order of magnitude improvement in performance over existing technologies in meeting NASA mission requirements
- **Technical Areas**
  - High rate networking and information systems
  - Optoelectronic systems for microwave communications
  - Optical mass memory
  - Microwave array antenna feed and control

PHOTONICS FOR I&CS

MILESTONES

- 1997 – 1 Gbit photonic low power network testbed
- 1998 – 1 Gbyte optical memory breadboard
- 1999 – Phased array antenna demonstration
- 2000 – Demonstrate100 Gbit/sec signal processor modulator / demodulator
- 2002 – Demonstrate a 3 Gbit/sec terabyte memory capacity network

RESOURCES

Budget ($,M)	1993	1994	1995	1996	1997
CURRENT	—	—	—	—	—
'93 REQUEST	—	—	5	6	7

- **Basis for Estimate**
  Augmentation needed to provide a technology base to satisfy mission requirements for high rate communications systems

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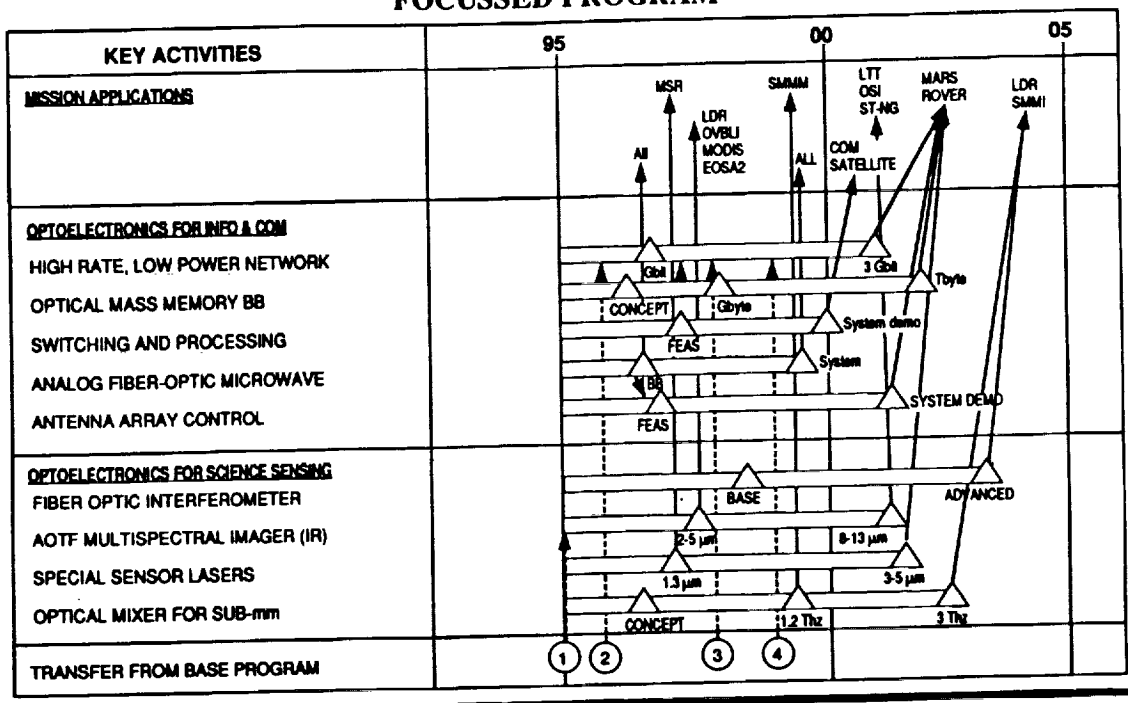
TECHNOLOGY ROADMAP/SCHEDULE

FOCUSSED PROGRAM



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INTEGRATED MILESTONES

FY 1991	DEMONSTRATE GROWTH OF InP MATERIAL, CONSTRUCT CHARACTERIZATION AND ANALYSIS SYSTEMS
	DATA ANALYSIS OF LDEF COMPLETE
FY 1992	DEMONSTRATE PASSIVE WAVEGUIDE COMPONENTS: WAVEGUIDES w/<1 dB/cm LOSS,
	OPTICAL CONTROL OF A SEGMENTED MIRROR
FY 1993	REAL-TIME GRAPPLING OF ARBITRARILY ORIENTED, MOVING OBJECTS
	EVALUATE AND TEST IMPROVED FIBER CABLE FOR SPACECRAFT
	ALGORITHMS FOR CONTROL OF A SPACE STRUCTURE FOR VIBRATION DAMPING
FY 1994	DEMONSTRATE AN INTEGRATED OEIC FOR A COM APPLICATION
	DEVELOPMENT OF FLIGHT DEMONSTRATION OF AUTONOMOUS VISION
	DEMONSTRATE FIRST OEIC INTEGRATION FOR COMMUNICATIONS NETWORK
FY 1995	COMPACT OPTICAL CORRELATOR
	CONTROL OF SPACE STRUCTURE MODELS AT 1000 Hz
	DEMONSTRATE COMPONENTS FOR AN AOTF SPECTROMETER
FY 1996	***DEMONSTRATE FEASIBILITY OF AN OEIC DEVICE FOR A 3 Gbps NETWORK***
	DEMONSTRATE FEASIBILITY OF AN OPTICAL SUB-mm MIXER
	DEMONSTRATE A STRUCTURE CONTROL PROCESSOR BREADBOARD
	DEMONSTRATE A SCANNABLE 10^{-9} METROLOGY SENSOR
FY 1997	***DEMONSTRATE AN OPTICAL PROCESSOR INTEGRATED INTO AN EOS DATA SYSTEM***
	DEMONSTRATE AOTF FOR 2.5 - 5 µm
	DEMONSTRATE 1 Gbit PHOTONIC LOW POWER NETWORK TESTBED
	DEMONSTRATE A 1 Gbit/sec LOW POWER NETWORK TESTBED
	DEMONSTRATE A DIODE LASER FOR SPECTROMETRY
FY 1998	***DEMONSTRATE SMART SKIN SENSORS FOR SPACE STRUCTURES***
	DEMONSTRATE 1.2 THz OPTICAL MODULATOR MIXER
	DEMONSTRATE BASELINE FIBER OPTIC SPACE INTERFEROMETER
FY 1999	***DEMONSTRATE OPTICAL CONTROL OF PHASED ARRAY ANTENNA***

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RESOURCES WITH AUGMENTATION

FUNDING IN M$

	91	92	93	94	95	96	97
BASE PROGRAM	0.6	0.6	3.6	4.6	5.6	6.6	8.6
SCIENCE SENSORS	—	—	—	—	4.6	4.9	6.8
PROCESSING AND COM	—	—	—	—	4.0	6.0	8.0
TOTAL:	0.6	0.6	3.6	4.6	13.6	16.9	22.8

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SUMMARY

- BASE AUGMENTATION REQUIRED TO DEVELOP CRITICAL MASS WITH RESEARCH ON NEW DEVICES AND INNOVATIVE CONCEPTS
- A NEED EXISTS FOR INITIATING A FOCUSED PROGRAM IN SUPPORT OF APPLICATIONS IN SENSING, COMMUNICATIONS AND INFORMATION SYSTEMS
- OPTOELECTRONICS WILL SIGNIFICANTLY IMPROVE PERFORMANCE, POWER AND WEIGHT FOR
  - MICROWAVE TRANSMISSION
  - HIGH-RATE NETWORKING
  - SPECIAL PURPOSE PREPROCESSING
- OSSA REQUIREMENTS DOCUMENT IDENTIFIES MANY APPLICATIONS, INCLUDING
  - MULTISPECTRAL IMAGING USING AOTF'S
  - SUBMILLIMETER DETECTION
  - PREPROCESSING FUNCTIONS

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APPENDIX

ADDITIONAL TECHNICAL INFORMATION ON PROGRAM ELEMENTS

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ADVANCED OPTICAL PATTERN RECOGINTION

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R&T SCOPE

Develop optical pattern recognition algorithms and systems to enable autonomous vision for in-space construction, inspection and exploration

PAYOFFS

Real-time (input scenes at ≥60 Hz, requiring >100 Gops) autonomous vision provided by a compact (200 cc, 1 kg), low power (<30 W) optical processor

BENEFITS

High-speed object recognition and spatial location to support a wide variety of construction, servicing and science activities, such as on-orbit construction and servicing, Lunar/Mars surface penetration for habitation, planetary science outpost servicing, and planetary science sample acquisition

TECHNICAL CHALLENGE

- Optical filters for object recognition invariant to rotation, scale and translation
- Demonstration of optical correlator-based real-time vision system controlling mobile robot in closed-loop grappling maneuvers
- Development of compact, low weight/power optical correlator

ADVANCED OPTICAL PATTERN RECOGINTION

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APPROVE BUDGET	FY91	FY92	FY93	FY94	FY95
ARC (K$)	100	125	125	125	125

MAJOR MILESTONES

FY 1991 Autonomous recognition and grappling of tools by lab robot
FY 1992 Increased optical filter sophistication - crowded fields, noisy inputs
FY 1993 Real-time grappling of arbitrarily oriented, moving objects
FY 1994 Development of flight demonstration of autonomous vision
FY 1995 Compact optical correlator

AGENCY THRUST Primary: Exploration
Secondary: Station platforms

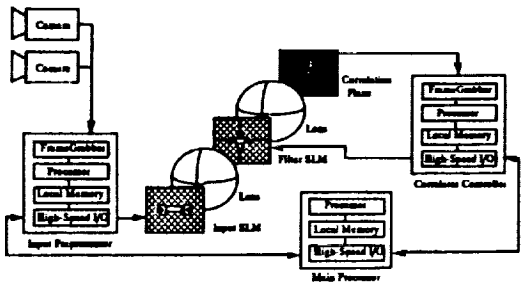
CENTERS ARC **MISSION** Lunar/Mars exploration
Space Station Freedom

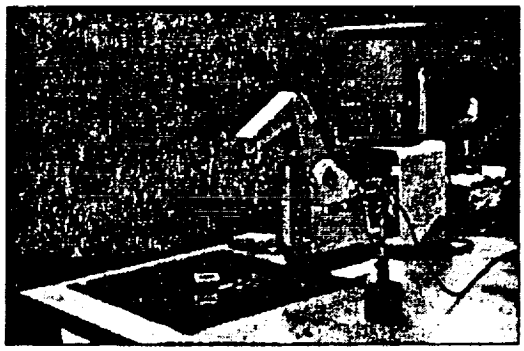
ADEQUACY OF RESOURCES

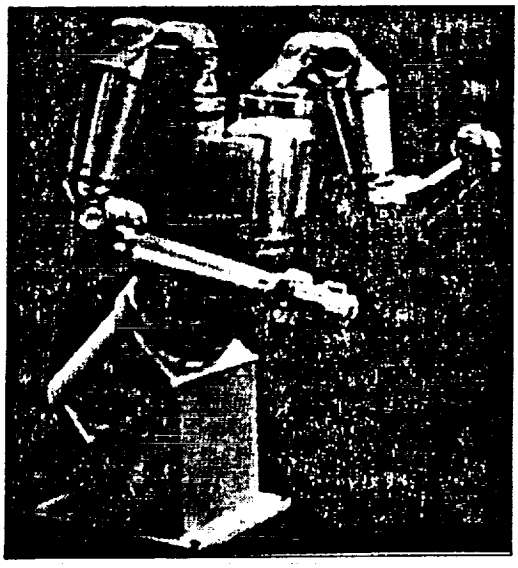
Nine member ARC civil servant team with unique experience in optical processor-based autonomous vision. Funding inadequate for flight hardware development.

CURRENT STATUS Current technology readiness level: 2/3

Advanced Optical Pattern Recognition







Optical correlator technology developed at ARC is applied to real-time machine vision problems.

- Performed identification and tracking of unmarked translated and rotated objects, allowing a robot to grasp the target objects.
- Machine vision system used over a remote video link to control an industrial robotics arm.

The Goal of this work is to develop vision processing systems applicable to in-space construction, inspection, and maintenance.

NASA
Ames Research Center

ADVANCED OPTICAL PATTERN RECOGNITION

Currently planned and future NASA missions have a great need for semi-autonomous and autonomous robotic systems capable of performing tasks which are either too dangerous or too expensive for humans to perform. Vision processing is one of the most computationally intensive tasks required of an autonomous robot and can benefit greatly from novel processing architectures designed to accelerate computationally expensive functions.

This goal of this research program is to apply the optical correlator filter technology developed at ARC to problems in real-time machine vision. The baseline problem is to autonomously identify, track, and grasp unmarked objects translating and rotating in space. Typical applications of such a machine vision system are in-space construction, inspection, maintenance, and repair.

A hybrid digital electronic/ analog optical robotic vision processing system has been developed for this task. It consists of two digital electronic stages and one analog optic stage. The digital image pre-processor handles functions such as stereo range processing and input image conditioning. The analog optical correlator performs the computationally intensive Fourier transforms for the filter correlation, under the control of a digital electronic filter database sequencer. The overall system monitoring and control is performed by the VME-based host processor. The filter database is a set of binary synthetic discriminant function filters organized in a search tree.

The system has been successfully tested on the two-dimensional version of the problem in a laboratory test bed, and has also been used with a remote video/data link to control a large industrial arm. In the test cases it has proved faster and more robust than a currently available all-digital electronic system. Although the current laboratory processor is too large for flight applications, current work towards a compact flight version of the processor is underway.

TECHNICAL CONTACT: Max Reid, ARC, (415) 604-4378 or FTS 464-4378
Butler P. Hine, ARC, (415)604-4379

OPTICAL CONTROL OF SPACE STRUCTURES

RC

OAET

R&T SCOPE

Develop high-speed optical matrix processing to control structural vibrations on space-based scientific instrument observation platforms

PAYOFFS

Real-time structural vibration control provided at a lower cost in power, weight and volume than possible with all-electronic processors. Single optical processor capable of controlling both adaptive optics and platform structures inspace

BENEFITS

Real-time vibration control will allow sensitive scientific instruments to be operated from SSF and EOS platforms. The approximately 1000 Hz damping required for SSF can be achieved with an optical matrix processor.

TECHNICAL CHALLENGE

- Demonstration of control of an adaptive mirror
- Algorithms for control of SSF structural model
- Development of high-speed, low weight/power optical matrix processor
- Demonstration of control at 1000 Hz

RC

OPTICAL CONTROL OF SPACE STRUCTURES

OAET

APPROVE BUDGET	FY91	FY92	FY93	FY94	FY95
ARC (K$)	75	75	75	75	75

MAJOR MILESTONES

FY 1991 Moderate speed laboratory breadboard optical matrix processor
FY 1992 Optical control of a segmented mirror
FY 1993 Algorithms for control of a space structure for vibration damping
FY 1994 High-speed optical matrix processor
FY 1995 Control of space structure models at 1000 Hz

AGENCY THRUST Primary: Science
Secondary: Station platforms

CENTERS ARC **MISSION** Mission to Planet Earth
Space Station Freedom

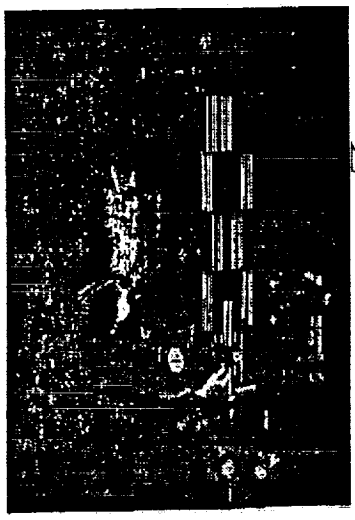
ADEQUACY OF RESOURCES

Nine member ARC civil servant team has a unique experience in applying optical matrix processors to control problems. Funding inadequate for flight hardware development.

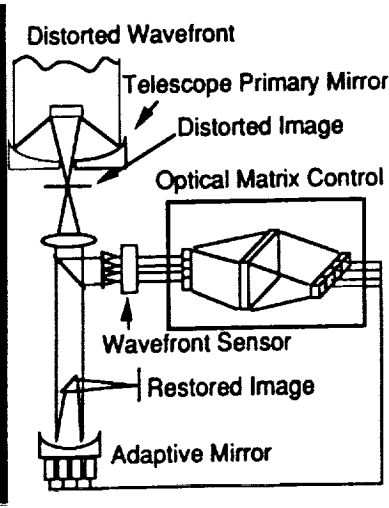
CURRENT STATUS Current technology readiness level: 2/3

Optical Control of Space Structures

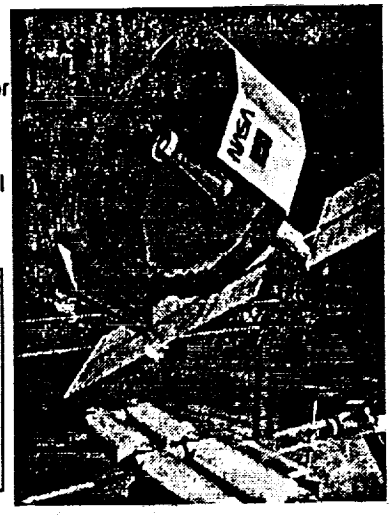
Built adaptive telescope control testbed



Designed control system for adaptive optics



Stabilization of space-based instrument platforms



Optical Matrix Processors can provide real time control of space structures and adaptive telescopes.

OMPs provide greater performance at lower power, mass, and volume than conventional computers.

Optical Control of Space Structures

The objective of the Optical Control of Space Structures development program is to apply research in high-speed optical matrix processing to provide real-time processing of control algorithms to damp structural vibrations on space based scientific instrument observation platforms. This research will lead to space qualifiable control processors for observation platforms. Initially work is to focus on the application of optical matrix feedback to the control of adaptable segmented mirrors, with the developments of this research subsequently applied to the stabilization of space based instrumentation platforms such as SSF and the EOS platforms. Optical processing offers greater performance at lower power, mass, and volume than conventional computers, as necessary for space applications.

Optical matrix vector multipliers provide a nearly instantaneous mechanism to compute feedback control signals. Optical processors are capable of taking an input vector, represented by an array of light intensities, and multiplying it by a matrix represented by a two dimensional array of absorbers. The light intensity representing the output vector is read by a photodiode array. The processing time for the entire product is the propagation time of the light.

Space Station Freedom structural support vibrations will need to be damped at approximately 1000Hz in order for sensitive science instruments to be operated on the platform. Similar techniques can also be used to compensate for the observational distortions of airborne and spaceborne Earth-observing platforms which use adaptive optics. The sensor values of either the platform positions or wavefront distortions are fed to the optical processor. The control algorithm is implemented by the matrix, and the control signals output by the optical processor are converted to electrical signals used either to drive the positioning jets of the platform or the mirror segments of the adaptable optics.

Currently, a test bed for the prototyping of optical matrix vector processors has been constructed. Control algorithms have been designed for a segmented mirror and the real-time control of a segmented mirror will be demonstrated. Work is proceeding in cooperation with the Langley Space Structures Control Laboratory to develop an optical processor for use on the platform control test beds.

Technical Contact: Max Reid, ARC, (415) 604-4378 or FTS 464-4378
Charles Gary, ARC, (415) 604-359

OPTOELECTRONIC INTEGRATED CIRCUITS

RC OAET

R&T SCOPE

This task will develop the technology for InP-based photonic/optoelectronic integrated circuits. Development will focus upon InP channel waveguide components, including straight waveguides, dispersive elemnt, and couplers. Subsequent work will include integration with active modulators, lasers and/or detectors. Discrete devices will be developed within a framework of a set of generic OEIC "building blocks". After component development, specific OEIC's for communication, signal processing (i.e. high speed switching) and science instruments will be developed.

PAYOFFS

Reduction of component and subsystem size, mass, and power by orders of magnitude. Increase in ruggedness and reliability via monolithic integration. Increased functionality via development of new OEIC-based architectures. Enables increased data rates, high parallelity (multiple channels); Reduces volume, mass and other demands upon spacecraft systems

BENEFITS

Micro -reduction of instruments and subsystems via monolithic integration will enable Mars microwave/Mars network missions. High-speed switching devices will enhance on-board computing/communications on EOS. Specialized OEICs, e.g., optical submm wave local oscillator, will enable terrestrial, atmospheric, and planetary explorations.

TECHNICAL CHALLENGE

- Low-loss waveguides and integrated optics components
- Low-threshold, single-mode, stable lasers and LEDs
- High-contrast, high-speed, low-insertion loss modulators
- High-speed detectors
- Monolithic integration of sources, waveguides, modulators, detectors in InP system

OPTOELECTRONIC INTEGRATED CIRCUITS

RC

OAET

APPROVE BUDGET	FY91	FY92	FY93	FY94
JPL (K$)	325	325	375	400

MAJOR MILESTONES

FY 1991	Demonstrate growth of InP material, construct characterization and analysis systems
FY 1992	Demonstrate passive waeguide components: waveguides w/<1 dB/cm loss, y-branches w/<1 dB excess insertion loss
FY 1993	Demonstrate active devices: single-mode lasers w/25 dB sidemode suppression ratio, detectors w/>1GHz response, modulators w/20 dB contrast ratio, <3dB insertion loss
FY 1994	Integrate devices into target OEIC's

AGENCY THRUST Primary: Operations
Secondary: Science

CENTERS JPL **MISSION** Mars network, EOS, SMMI

ADEQUACY OF RESOURCES

Current plan supports development of basic growth, characterization, analysis via leverage from existing Microdevices Laboratory and ~%500K funding from DoD agencies. Addition of Fe source to reactor (to grow semi-insulating InP material) and expansion to specific applications requires significant funding augmentation in future FYs.

CURRENT STATUS Technology readiness level: 2/5

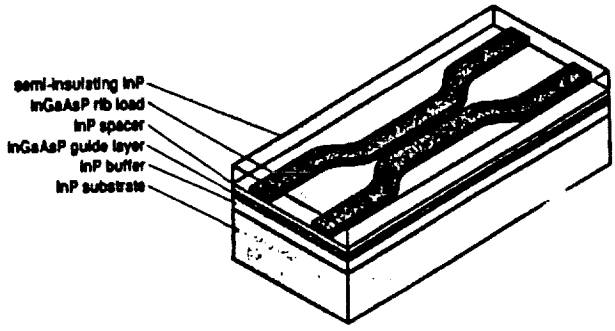
JPL

Optoelectronic Integrated Circuits

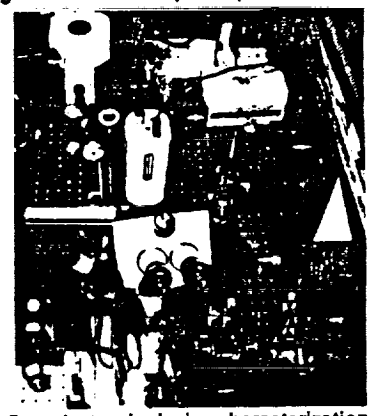
Photonic and Optoelectronic Integrated Circuits

- Device growth, design, processing, characterization
- Modified existing reactor for InGaAsP/InP growth
- Design and initial construction of measurement testbed
- Completed multipurpose complex slab waveguide analysis program
- Device processing carried out in existing JPL Microdevice Laboratory, including etching, metallization, dielectric deposition, optical and e-beam lithography

Metal-Organic Chemical Vapor Deposition (MOCVD) reactor



Schematic of InP channel waveguide directional coupler



Optoelectronic device characterization

Optoelectronic Integrated Circuits

This task will develop the technology for InP-based photonic/optoelectronic integrated circuits. Development will focus upon InP channel waveguide components, including straight waveguides, dispersive element, and couplers. Subsequent work will include integration with active modulators, lasers, and/or detectors. Discrete devices will be developed within a framework of a set of generic OEIC "building blocks." This technology will then be applied to specific applications, including one or more of: a monolithic fiber ring gyro chip; an optical submm wave local oscillator; a high-speed optical switching network; and/or wavelength-division multiplexed receiver/transceiver.

Photonic and optoelectronic integrated circuits represent device technologies with the potential to meet a broad range of future telecommunication, computing system, and instrumentation/ sensor needs. ("Photonic" integrated circuits are generally considered to be circuits that process light directly, such as polarizers and couplers; "optoelectronic" integrated circuits are those that integrate conventional electronic circuitry with optical inputs and/or outputs.) As is true for integrated electronics, monolithic integration of photonics and optoelectronics offers significant advantages over hybrid circuits in compactness, mechanical reliability, possible performance improvements resulting from reduced parasitics, and potentially significant reductions in cost, particularly in the case of arrays.

The task will be initially be broken up into four phases:
(1) Construction of a photonic characterization facility within JPL's Microdevices Laboratory to provide standard analysis of OEIC components.
(2) Development of growth techniques for InP-based heterostructure waveguides and related OEIC components using metal-organic chemical vapor deposition (MOCVD)
(3) Fabrication and characterization of single OEIC components (e.g., waveguides, couplers, amplifiers, switches).
(4) Small-scale integration of OEIC components into test circuits and investigation of their interactions.

Status:
• Growth—the existing MOCVD reactor has been redesigned to accomodate the growth of P-containing compounds (using PH_3 gas as a source). A new glovebox, reactor vessel, and associated instrumentation has been designed, bid, and procured. Installation will begin in 8/91.
• Characterization—A computer-controlled characterization system to measure pulsed near field, far field, waveguide loss, modes, and other optoelectronic parameters has been designed and procured. Installation is progressing as parts are received.
• Analysis—A general-purpose waveguide analysis computer program to calculate the effective index, loss, fill factors, and other modal properties of arbitrary slab waveguides has been written and debugged.

Technical Challenges
The initial thrust is the establishment of a comprehensive fabrication/test/analysis facility; integration of multiple devices requires a complete capability for each device in the OEIC. Realization of the benefits of OEICs requires the ability to fabricate several types of device (and often multiple devices of each type) on a single chip. The process of integration thereby places conflicting demands on the device structure and process. A major challenge is to achieve near-state-of-the-art performance at the device level with a device structure that is a compromise between the different device requirements. A secondary challenge is achieving uniformity over large areas and repeatability from wafer to wafer; as the level of integration increases, the tolerance for nonuniformities and device yield decreases drastically.

Technical contact: Robert J. Lang, JPL, (818) 354-5724

SPACE ENVIRONMENT EFFECTS ON FIBER OPTICS

RC

OAET

R&T SCOPE

Evaluate changes to samples of fiber optic cables flown on the LDEF. Interpret the LDEF data, related laboratory data and analytical models for fibers and components to recommend system designs and testing approaches. Investigate the causes of environmental changes and devlop approaches to reduce them.

PAYOFFS

Reduced risk from the use of new fiber optic technology in space systems.

BENEFITS

An understanding, based on laboratory data and space exposure of low dose rate long term radiation darkening, temperature effects and polymer aging in fiber optic systems. The results will enable realistic environmental design, and development of improved devices.

TECHNICAL CHALLENGE

- Reliable projection of short term experimental results to predict performance over a 5 to 20 year mission duration.
- Product improvement, which is probably impurity dependent, in semiconductor and glass technology

SPACE ENVIRONMENT EFFECTS ON FIBER OPTICS

RC

OAET

APPROVE BUDGET	FY91	FY92	FY93	FY94
JPL (K$)	125	150	175	175

MAJOR MILESTONES

FY 1991 Data analysis of LDEF complete
FY 1992 Complete survey, make recommendations for design
FY 1993 Evaluate and test improved fiber cable
FY 1994 Test system evaluation

AGENCY THRUST Communication and data systems

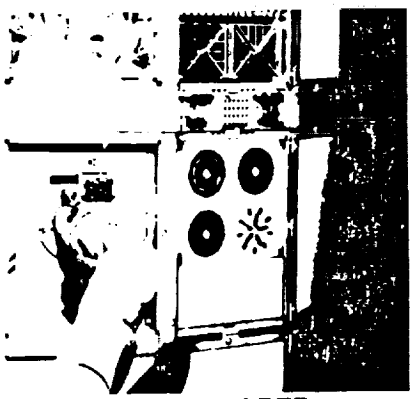
CENTERS JPL **MISSION** All missions; Mars exploration EOS, Lunar base

ADEQUACY OF RESOURCES

Present level is adequate, but late receipt of funds has delayed LDEF data analysis in FY91. Promising results will mean that increased resources for contractor support will be needed for product improvement in future years.

CURRENT STATUS System technology level: 4-5
Environmental effects level: 2-3

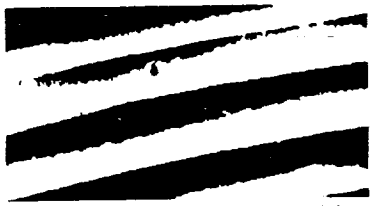
Long Duration Exposure Facility
JPL Fiber Optic Experiment No. S-0109



Experiment on LDEF being brought into Shuttle Payload Bay

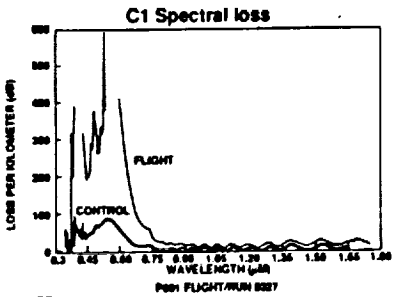
- Objective: to observe the effects of the space environment on fiber cable and connector samples
- Recovery: the LDEF was recovered in January 1990 after 5 1/2 years in space
- Configuration: 10 fiber cable samples flown on LDEF; 4 external and 6 internal fiber performance measured before and after exposure
- Results: all fiber samples are functional; best fibers are unchanged

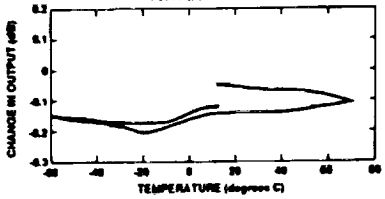
Contamination on a connector termination



Example of a micrometeroid hit on fiber cable

C1 Spectral loss





DESIGN ISSUES FOR FUTURE SYSTEMS

- Radiation darkening
- Temperature effects
- Connector contamination
- Polymer aging

SPACE ENVIRONMENT EFFECTS ON FIBER OPTICS

The objective of this task is to understand, through experimental and analytical work, the effects of the space environment on the components of a fiber optic system. These effects include, primarily, radiation damage, temperature effects, and the long-term effects of space on the polymers used in fiber cables and as cements or packaging elements In fiber and semiconductor devices.

The current work, illustrated on the accompanying graphic, involved observing and interpreting changes to ten fiber optic cable samples flown on the LDEF. The LDEF was recovered in January 1990 after 5 1/2 years in low-earth orbit, and is a unique source of information about the effects of the space environment on the samples it carried. Four of the cables were external, and suffered extreme temperature cycling and 2π exposure to space radiation. The remaining six samples were mounted internally in a protected environment. Measurements are not complete but it appears that radiation darkening may be adequately predicted by laboratory testing allowing annealing of the damage to occur over a 1-2 day period after dosing. One external sample did not exhibit a measurable increase in loss, (<0.1 db, or 4 db/km) indicating that radiation darkening is a design issue only for long, fully exposed cable runs. Other issues are temperature induced loss changes, and the possibility of connector contamination frome the volaties in cabling materials.

Future work is needed to relate the LDEF observations to a large amount of data obtained in laboratory experiments, and to recommend approaches to system design and qualification testing.

In addition, investigations are needed to determine if improvements can be made to fibers through better material choices or through control of unknown impurities. The general understanding of the causes of radiation loss is limited, and the data is inconsistent. A reliable approach also must be developed to conduct accelerated testing, since some missions will be long enough that real-time testing is not practical.

Finally, similar investigations must be extended to include the light sources and detectors used in lightwave systems.

Technical contact: Alan Johnston